



AERC 2018



April 17 – 20, 2018
Sorrento, Italy

12th Annual
European Rheology
Conference

XV Meeting of the
Italian Society of
Rheology



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Welcome to AERC 2018 in Sorrento

We welcome you to the joint 12th Annual European Rheology Conference (AERC) and XV Italian Society of Rheology (SIR) Conference in Sorrento (Napoli), Italy, 17-20 April 2018. The joint meeting is addressed to rheologists of all scientific backgrounds, from academy to industry and government research centres, aiming at sharing ideas in a friendly, informal atmosphere. The SIR meetings are organized biannually all around Italy and provide an excellent platform for networking with old and new colleagues, including the newcomers to the field, in the same spirit of the AERCs. The conference program features 12 parallel sessions spanning diverse, highly relevant rheological topics listed in the following page, with 12 keynote lectures, and 3 plenary presentations. Overall, there are about 600 participants and more than 500 accepted abstracts (oral and poster) with authors coming from 50 countries, a sign of the growing scientific interest in rheology. With about 30% of the contributions from outside Europe, the conference can be considered a worldwide forum of the rheological community.

The interest in this event is also shown by the 19 sponsors, exhibitors and endorsing associations and institutions, which are listed in this book. We wish to express special thanks to the European Society of Rheology and to the Italian Society of Rheology for giving us the honour to host AERC 2018 and XV SIR conference. The generous contribution of our sponsors and the financial support from SIR are also gratefully acknowledged. It would be too long to list all the people who made this event possible. Just to cite some of them, we like to thank the session chairmen, the local organizing committee, the instructors of the short rheology course, the webmaster of the conference website and the system administrator of the abstract submission portal, the jury of the paper awards, and the staff of students (the blue shirts). Their hard work was essential for the conference organization. We also wish to thank the Mayor of the city of Sorrento for making the Town Hall available to the welcome reception and the Cathedral of Sorrento for hosting the concert before the social dinner.

We wish to conclude this brief introduction with a few words about the conference venue. Sorrento is a renowned touristic city located in an extraordinary Mediterranean landscape where sea and mountain, deep valleys and citrus groves alternate along the coast. Sorrento is in an ideal position to enjoy a range of touristic attractions, from nature to culture, thermal spas, naturalistic walks, and to explore the nearby cities of Naples, Pompei, Ercolano, Ischia, Capri, Positano, Amalfi, Ravello, etc.

It is our privilege to welcome you to the joint 12th AERC-XV SIR conference in Sorrento, and we are strongly committed to spend all our efforts to ensure a successful conference.

The AERC 2018 chairs,

Mario Minale, Stefano Guido, and Giovanni Ianniruberto

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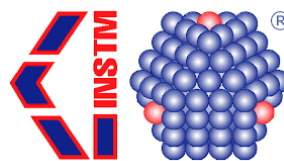
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Scientific Sessions and Chair Persons

- **Blends, Emulsions, Foams & Interfacial Rheology**

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- **Porous Media, Geo Fluids, Crude Oil & Derivatives**

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- **Colloids & Suspensions**

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- **Food, Pharmaceuticals, & Cosmetics**

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- **Living & Active Matter**

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Antonio De Simone, *Scuola Internazionale Superiore di Studi Avanzati*

Gerhard Gompper, *Forschungszentrum Jülich*

- **Non Newtonian Fluid Mechanics & Flow Instabilities**

Patrick Anderson, *TU Eindhoven*

Peter Olmsted, *Georgetown University*

Fernando Tavares de Pinho, *University of Porto*

- **Polymer Solutions & Melts**

Yuichi Masubuchi, *Nagoya University*

Angel Moreno, *University of Pais Vascos*

Daniel Read, *University of Leeds*

- **Solids, Glasses, & Granular Materials**

Philippe Coussot, *University Paris-Est*

Joe Goddard, *UC San Diego*

Luigi Grassia, *University of Campania "Luigi Vanvitelli"*

Program Overview – Day 1

Apr 18th	Wednesday						
08:30	Opening Ceremony (Sirene)						
09:00	Plenary talk (PL1) - M. Cates - Flow of dense suspensions: Protocols to prevent jamming (Sirene)						
	Sirene	Ulisse	Tritone	Nettuno 1	Nettuno 2-3	Nettuno 4	Nettuno 5-6
10:00	CS1 - T. Libertio - Rheology of CaCO3 paste: the solution's physico-chemical role	NF1 - J. Ma - The behaviours of the elastic capsules in viscoelastic fluid Poiseuille flow with finite inertia	SM1 - R. Ewoldt - Intrinsically-nonlinear rheometry	MN1 - H. Bodiguel - Flow of foam in model porous media	SG1 - K. Trachenko - New understanding of collective modes and thermodynamics of the liquid state	PG1 - F. Marchesini - Crude oils: wax crystallization and rheological behavior	BE1 - J. Hong - Interrelationship between bulk and interfacial rheology of emulsions stabilized with clay particles
10:20	CS2 - M. Cidade - Rheological properties of injection grouts incorporating nano-silica	NF2 - A. Sucena - Numerical study of three-dimensional multiphase flows of viscoelastic fluids with the Level-Set ...		MN2 - J. Kim - Flow instability and mixing in dilute polymer solution in a gear-shaped microchannel	SG2 - R. Bonnecaze - Shear-Induced Structural Rearrangement in Jammed Suspensions of Soft Particle Glasses	PG2 - B. Mena - Lubricated transport of very viscous oil in pipes	BE2 - A. Kannan - Dilatation mechanics and bubble coalescence of monoclonal antibody interfaces
10:40	CS3 - Y. Grasselli - Discontinuous shear thickening and stick-slip oscillations tuned by a magnetic field	NF3 - D. Izbasarow - Dynamics of an elastoviscoplastic drop in a Newtonian medium under shear flow	SM2 - T. Schweizer - Non-linear shear rheology of dendronized polymethacrylate melts studied with ...	MN3 - S. Yang - Realization of multiple-line particle focusing under viscoelastic flow	SG3 - M. Gruber - The delocalization transition in a colloidal glass	PG3 - C. Carotenuto - Effect of solvents on the asphaltene aggregation in a heavy crude oil	BE3 - L. Walker - Impact of adsorbed colloidal complexes on fluid-fluid interfaces
11:00	Coffee Break						
11:30	CS4 - A. Papadopolou - Particles in complex formulations: rheology, dynamics and microstructure	NF4 - G. D'Avino - Numerical simulations on the dynamics of a spheroid in a viscoelastic liquid in a slit microchannel	SM3 - Q. Huang - Novel flexible polystyrenes show increased tensile strength	MN4 - V. Preziosi - A novel microfluidic technique to measure interfacial tension of emulsions	SG4 - A. Furukawa - Shear thinning in glassy liquids	PG4 - P. de Souza Mendes - Water-in-crude oil emulsions: stability, separation, bulk rheology, and interfacial rheology	BE4 - A. Huerre - Transient string formation in colloid monolayers at fluid interfaces under ultrafast deformation
11:50	CS5 - O. Ozenda - A new elastoviscoplastic model for highly concentrated suspensions of solid ...	NF5 - P. Capobianchi - Thermocapillary motion of a Newtonian droplet in a viscoelastic fluid under Stokes flow ...	SM4 - Y. Matsumiya - Uniaxial extensional viscosity of Poly(n-alkylstyrenes)	MN5 - M. Villone - Determination of the mechanical properties of soft particles through a non-invasive microfluidic ...	SG5 - L. Ramos - Microscopic dynamics during the yielding of a dense glass of soft spheres		BE5 - N. Baldino - Surface behaviour of vegetable protein by pendant drop method
12:10	CS6 - R. Seto - Extensional versus shear rheologies for dense suspensions	NF6 - S. Kumar - Transfer of rate-thinning and rate-thickening liquids between separating plates and cavities	SM5 - T. Shahid - Assessing the monomeric friction reduction mechanism with monodispersed ...	MN6 - E. André - Drop deformation in microfluidics for viscosity measurements	SG6 - R. Zia - The colloidal glass transition: Relaxing into arrest	PG5 - G. Fuller - Spontaneous emulsification in the presence of asphaltenes	BE6 - M. Heuzey - Interfacial rheology of bacterial biofilms
12:30	CS7 - R. Chacko - Vorticity banding in dense suspensions	NF7 - A. Hojeij - Hydrodynamic mixing of yield stress fluids by gas injection	SM6 - R. Hodgkinson - The effect of extensional flow on shear viscosity	MN7 - A. Lindner - Microfluidic in situ mechanical testing of flexible particles	SG7 - G. Rossi - Dry granular flows rheology: experimental investigation and particles simulations	PG6 - S. Khalilnizhad - Experimental investigation of the effect of hydrophilic nanoparticles ...	BE7 - M. Picicelli - Dilatational viscoelasticity of a polymer multilayer system at the air-water interface
12:50	Lunch Break						
14:20	CS8 - D. Parisi - Effects of shape on the dynamics of concentrated solutions of polymer-grafted ...	NF8 - M. De Corato - Acoustically enhanced bubble removal from yield stress fluids	SM7 - M. Wagner - A novel criterion for brittle fracture of entangled polymer liquids	MN8 - R. Cerbino - Differential dynamic microscopy micro-rheology: frequency-dependent moduli without tracking!	SG8 - D. Harris - A Cosserat plasticity model for the deformation and flow of granular materials and soils	PG7 - R. Maitri - Lateral particle migration in random porous media	BE8 - A. Bykov - Dilational surface rheology of pulmonary surfactants in broad range of surface pressures
14:40	CS9 - J. Ruiz-López - Biaxial Extensional Rheology of Shear Thickening Fluids	NF9 - I. Karimfazi - Analysis of flow development in yield stress fluids	SM8 - A. Borger - Molecular conformation of star polymers in nonlinear extensional flow followed ...		SG9 - L. Sardo - Low impact cratering on granular beds under low gravity	PG8 - F. De Vita - Dynamics of elastoviscoplastic flows in porous media	BE9 - A. Audebert - Topological rearrangements and surface rheology : a multi-scale approach on dairy ...
15:00	CS10 - J. Park - Influence of latex SBR binder on the rheological and adhesive properties of ...	NF10 - S. Hatzikiakos - Dynamic Slip of Polydisperse Linear Polymers using Partitioned Plates	SM9 - M. Abbasi - Rheological properties of model comb polystyrenes with entangled and unentangled ...	MN9 - L. Mason - Investigating the viscoelastic properties of complex materials and cells to study cancer ...	SG10 - T. Barker - Well-posed continuum equations for granular flow	PG9 - S. Sinha - Crossover from linear to non-linear rheological behavior of two-phase flow ...	BE10 - S. Tcholakova - Shear and dilatational viscoelasticity of saponin adsorption layers
15:20	CS11 - M. Liard - Jet instability of a shear-thickening suspension of solid particles	NF11 - F. Mollica - Exit effects in the wall slip of polymeric concentrated suspensions	SM10 - J. Madsen - Exploring the Dependence of Polymer Architecture on Rheology	MN10 - E. Bradt - Micro-rheology of biofluids	SG11 - R. Delannay - High speed confined granular flows down inclines: numerical simulations	PG10 - L. Paduano - Apparent wall slip of viscoelastic fluids with roughened geometries: a porous ...	BE11 - J. Bergfreund - Effect of oil hydrophobicity on adsorption and rheology of β -lactoglobulin at ...
15:40	CS12 - B. Schroyen - High frequency rheology of colloidal dispersions: from hard to soft, ...	NF12 - P. Coussot - Yielding, wall-slip and instability, of yield stress fluids in "true" elongation (experiments)	SM11 - F. Stadler - Understanding and Classifying Thermorheological Complexity for Linear and Branched ...	MN11 - R. Hiedema - Polymer-polymer interaction in a flow measured by a scanning probe microscopy	SG12 - T. Trewhela - Size segregating intruders in oscillating shear cells	PG11 - M. Geri - Controlled formation of hydrate suspensions via frozen emulsions	BE12 - J. Vermant - Towards rheology of lipid bilayers
16:00	Coffee Break						
16:30	CS13 - R. Radhakrishnan - Understanding shear thinning of dense suspensions through simulations	NF13 - P. Bourrianne - Diving into a shear-thickening bath	SM12 - S. Pan - Entangled double-stranded and single-stranded DNA soft gels under LAOS: Nonlinearity ...	MN12 - G. Nava - Viscosity of a DNA transient network: Newtonian to shear thinning transition	SG13 - A. Valance - Compressibility regularizes the $\mu(I)$ -rheology for dense granular flows	PS1 - E. Del Gado - Network topology in soft gels: hardening and softening materials	BE13 - M. Gottlieb - Viscous, elastic, and viscoelastic interfaces - the effect of polymer chain flexibility
16:50	CS14 - T. Gibaud - Dynamics of shear-thickening dispersions	NF14 - C. Williams - Molecular dynamics simulations of shear-thickening behaviour using a ...	SM13 - J. Den Doelder - Modeling the kinetics and rheology of thermo-mechanically degraded LDPE	MN13 - F. Tesser - Chiral micro-particles interacting with viscous shear flows	SG14 - N. Gaudel - Granular avalanches down vibrated inclines: an experimental and numerical approach		BE14 - M. Rubio - The bicone interfacial shear rheometer revisited: flow field based data processing ...
17:10	CS15 - R. O'Neill - Liquid migration during extrusion of concentrated shear thickening suspensions	NF15 - I. Frigaard - Inline settling of particles in a Bingham Fluid	SM14 - D. Tsallikis - Melt rheology of ring poly(ethylene oxide) melts and comparison with experimental data	MN14 - S. Haward - Viscoelastic Poiseuille flow through wavy-wall microchannels	SG15 - M. Korhonen - Interparticle friction controls submerged granular flows in simulations	PS2 - A. Pommella - Microstructural failure under creep of an agarose gel investigated by space ...	BE15 - F. Martínez-Pedrero - Linear shear rheology of aging β -casein films adsorbing at the ...
17:30	CS16 - J. Royer - Contact forces and particle interactions in shear thickening suspensions	NF16 - M. Zare - Hydrodynamic instabilities in displacing a viscoplastic fluid with a Newtonian fluid	SM15 - C. Das - Tube theory modelling for the linear rheology of polydisperse linear polymers	MN15 - L. Ducloux - Secondary flows of viscoelastic fluids in curved microchannels	SG16 - T. Kranz - Rheology of dense granular fluids from first principles	PS3 - M. Le Merrer - Wall slip regimes in suspensions of polymer microgels	BE16 - P. Moldenaers - Understanding the foamability and mechanical properties of foamed ...
17:50	CS17 - S. Jesinghausen - Wall slip and concentration measurements by means of modified PIV methods	NF17 - M. Daneshi - Experiments on obstructed viscoplastic flow in a thin slot	SM16 - H. Taghipour - Nonlinear shear behavior in binary blends of linear polymers with well-separated ...	MN16 - J. Morillas - Steady shear flow behavior of magnetorheological fluids in microchannels	SG17 - J. Sun - Rheology of dense granular materials under steady or dynamic shear	PS4 - J. Van der Gucht - Strand plasticity governs fatigue in colloidal gels	BE17 - E. Di Maio - The role of elasticity in pore wall breaking
18:10	Poster Session with Reception sponsored by Anton Paar (Foyer Sirene)						
20:00	End						

Program Overview – Day 2

Apr 19th	Thursday							
08:30	Plenary talk (PL2) - M. Cloitre - Microscopic design of soft colloidal materials (Sirene)							
	Sirene	Ulisse	Tritone	Nettuno 1	Nettuno 2-3	Nettuno 4	Nettuno 5-6	
09:30	CS18 - H. Goswami - Rheology of jammed suspensions of anisotropic particles	NF18 - A. Pereira - Buckling of viscoplastic fluid filaments under compression stresses	MN17 - A. Domingues - Inertial and elastic flow instabilities in a mixing-separating microfluidic device	NF52 - M. Hulsen - Stable simulation of viscoelastic fluid flow using integral models	SG18 - X. Jia - Acousto-Rheology: probing and triggering of unjamming in dense granular media	P55 - K. Remenitz - Linking extensional deformation of taghish mucin hydrogels to their environment and dynamic ...	BE18 - C. Mitrias - Simulation of bubble growth during the foaming process	
09:50	CS19 - J. Férec - A rheological constitutive model for semiconcentrated rod suspensions in Bingham fluids	NF19 - K. Cho - Equations of motion from the nonequilibrium statistical mechanical theory for material ...	MN18 - S. Shin - Inertial micropump in microfluidics	NF53 - A. Mackay - Theoretical & computational modelling of compressible viscoelastic fluids		P56 - S. Goudard - Viscoplastic materials based on surfactant-activated microgels	BE19 - U. Handge - Strain-softening of polystyrene-block-poly(4-vinylpyridine) diblock copolymers in melt ...	
10:10	CS20 - M. Ellero - Modeling, simulation and rheology of particulate systems interacting with a viscoelastic matrix	NF20 - K. Sato - Direct observation of orientation distributions of actin filaments in a solution undergoing ...	MN19 - F. Del Giudice - High throughput viscoelastic ordering of particles in a straight microfluidic channel	NF54 - A. Rüttgers - Sparse grids - an approach to reduce the complexity of multiscale simulations	SG19 - J. Goddard - Dissipation potentials and gradient regularization of granular Hadamard instability	P57 - S. Aime - Power law viscoelasticity of a fractal colloidal gel	BE20 - P. Martiny - Linear and non-linear mechanical properties of solid closed and open cell foams	
10:30	CS21 - P. Kuzhir - Dimorphic magnetorheological suspension based on sepiolite needles	NF21 - J. Adams - Transient shear banding in the nematic dumbbell model of liquid crystalline polymers	MN20 - R. Georgiev - Tuning particle translation and rotation in shallow microfluidic channels via particle ...	NF55 - C. Balan - Fluid - spherical particles interaction in confined domains: the glass bead game	SG20 - A. Arseni - 3D simulation of dense granular flow in a rotating drum	P58 - R. Cabriolu - Precursors to failure in a gel forming system	BE21 - J. Sepulveda - Rheological properties of biosourced foams produced by microchannels at high ...	
10:50	Coffee Break (sponsored by Malvern)							
11:20	CS22 - F. Fneich - Structure and rheology of cellulose nanofibrils suspensions and hydrogels: effect of volume fraction ...	NF22 - M. Jenny - Shear-banding and Taylor vortices in thixotropic yield stress fluids according a structural parameter ...	SM17 - B. Khomami - Molecular rheology of entangled polymeric fluids: Understanding bulk flow behavior ...	NF56 - S. Claus - A cut finite element method for multi-phase viscoelastic flows	SG21 - Y. Chung - Granular column collapse in fluid: combined CFD-DEM modelling and experimental validation	P59 - Y. Leong - Microstructure of Hectorite Clay Gels with Long Ageing Timescale	BE22 - V. Schmitt - Use of rheology to determine water fluxes and encapsulation efficiency in double emulsions	
11:40	CS23 - E. D'Ambrosio - Shear-induced Resuspension of spherical particles in a Couette device: Measurement of ...	NF23 - V. Vasisht - Inertia induced permanent shear band instability of dense anisotropic systems	SM18 - J. Takimoto - Stress relaxation of polymer melts under fast shear flow: a simulation study	NF57 - K. Zografos - A two-phase viscoelastic solver considering a diffuse interface model	SG22 - M. Le Goff - Finite shear rate critical point in a mesoscopic model of flowing disordered materials	P510 - C. Oelschlaeger - Structural, macro- and micro-mechanical properties of supramolecular bi-component ...		
12:00	CS24 - A. Zinchenko - Flocculation of non-Brownian suspensions	NF24 - L. Noiret - Thermal shear banding observed in ordinary low molecular weight polymer melts	SM19 - Y. Masubuchi - Stress undershoot of entangled polymers under fast startup shear flows in primitive chain...	NF58 - S. Ingelsten - Simulating the dispensing of complex rheological fluids on arbitrary geometries using...	SG23 - L. Gömze - Rheological principles of development self-healing ceramic based composite materials with ...	P511 - J. Godefroid - Dynamics of alginate/ceramic suspension droplets impacting a bath of calcium ions	BE23 - M. Goavec - Rheology and structure of drying emulsions	
12:20	CS25 - N. Wagner - Advances in thixotropy modeling of suspensions applied to fumed silica, carbon black ...	NF25 - H. Jin - Effect of non-local stress on shear banding flow in confined geometry : Numerical simulation ...	SM20 - G. Milano - Exploring polymeric materials with multiscale simulations for interface engineering	NF59 - M. Cracco - Linear stability and transient behaviour of viscoelastic fluids in boundary layers	SG24 - K. Kang - Non-uniform flow in soft glasses of DNA-virus suspensions	P512 - S. Recktenwald - Elongational flow behavior of low concentrated surfactant solutions	BE24 - L. Paduano - Flow-induced nanostructure of gelled emulsions: a small-angle neutron scattering study	
12:40	CS26 - J. Schmitt - TEMPO-oxidized cellulose nanofibrils: probing the mechanisms of gelation via SAXS ...	NF26 - S. Fielding - Edge fracture versus shear banding in entangled polymeric fluids	SM21 - P. Bacova - Computational design of nanostructured polymer materials: Atomistic simulations of ...	NF60 - K. Housiadas - The singularity of the Oldroyd-B model for the viscoelastic flows past a cylinder and past a sphere	SG25 - O. Alen - Time-dependent behavior of polymer-metal composite stripe for magnetic encoders	P513 - N. Denkov - Control of surfactant solution rheology using medium-chain cosurfactants	BE25 - M. Barra - Monitoring complex fluids microstructure by using organic electrochemical transistors	
13:00	Lunch Break							
14:30	CS27 - S. Hormozi - The interaction of spherical particles in simple-shear flows of yield stress fluids	NF27 - O. Manero - Localized structures in rheologically complex fluids	SM22 - H. Watanabe - Viscoelastic and dielectric relaxation of reptating type-A chains affected by head-to-head ...	FP1 - M. Grassi - Swelling of viscoelastic matrices by viscoelastic fluids	IP1 - N. Grizzuti - Blending microcrystalline and resin constituents of a chewing gum: dependence of ...	P514 - G. Park - Exploring Shear Thickening of Telechelic Associating Polymers through Stochastic Simulations	BE26 - M. Denn - Carbopol: from a simple to a thixotropic yield stress fluid	
14:50	CS28 - S. Kumar - Rheology and electric field response of fumed nanoparticles in nematic liquid crystal suspensions	NF28 - G. Georgiou - Solutions of pressure-driven flows of yield stress fluids with pressure-dependent ...	SM23 - F. Zhuge - Shear and extensional rheology of entangled bulk polymers functionalized with metal-ligand ...	FP2 - D. Gaudino - Drug release in a micellar solution: a study based on DWS microreology		P515 - P. Bertsch - The Self-Assembly and Aggregation of Nanocrystalline Cellulose in two and three Dimensions	BE27 - M. Jalaal - Viscoplastic water-entry	
15:10	CS29 - J. Mala - Rheology and microstructure of colloidal suspensions in confined flows	NF29 - A. Syrakos - Simulation of the flow in fluid dampers: effects of fluid elasticity and plasticity	SM24 - T. Tomkovic - Rheology and Capillary Flow of Ionomers	FP3 - F. Lupi - A rheological and microstructural characterisation of MAGs organogel at different stearate/...	IP2 - C. Xu - How rheological properties affect fine line screen printing of pastes: a combined rheological and ...	P516 - P. Sudersan - Unusual self-assembly behavior of polyelectrolytes	BE28 - F. Léonardi - From recycled polymers waste to microfibillar composites	
15:30	CS30 - A. Giuliani - Interfacial slip of colloidal suspensions investigated by near-wall dynamic light scattering	NF30 - T. Divoux - Pattern formation and fingering instability in carbon black gels	SM25 - M. Shvokhin - Linear and non-linear rheology of hyper-branched EAA-cb-PP comb block copolymers	FP4 - S. Varghese - Controlled release of hydrophobic drug-biopolymer using Fe-based nano biocomposite ...	IP3 - M. Kralcic - Assessment of reinforcement in polymer nanocomposites using cumulative ...	P517 - B. Wolf - Viscosity of polyelectrolyte solutions as a function of composition in the absence and in ...	BE29 - Y. Niu - Effects of ionic liquids and thermal annealing on the rheological behavior and electrical properties ...	
15:50	Coffee Break							
16:20	CS31 - V. Labelette - Rheology of a suspension of colloidal plate-like particles with repulsive electrostatic ...	NF31 - P. Anderson - Elastic instabilities in injection molding	SM26 - H. Winter - Viscoelasticity of microphase separated brush block copolymers - molecular ...	FP5 - R. Pasquino - Zeolites as support for anti-inflammatory drugs: rheology as a tool to track the ...	IP4 - R. Kádár - Linear and nonlinear shear rheology of low percolation graphene polymer ...	LA1 - R. Winkler - Dynamics and rheology of active particles in microchannel flows	BE30 - R. Gallu - Rheology and morphology relationships of polyurethane modified bitumen	
16:40	CS32 - C. Lang - Polydispersity influences on the shear thinning behavior of rodlike colloids	NF32 - C. Barentin - Wetting of yield-stress fluids	SM27 - A. Louhichi - Shear strain hardening and unusual stress relaxation after flow cessation of ...	FP6 - C. Zhang - The rheology of environmentally friendly personal care products	IP5 - R. Andrade - Rheology and processing of polymer nanocomposites with graphene ...	LA2 - D. Fedosov - Formation and dissociation of VWF-platelet aggregates in blood flow	BE31 - E. Helal - Effect of graphene on the rheological behavior of linear low density polyethylene/ethylene ...	
17:00	CS33 - P. Ilg - Magnetic nano-colloids in viscoelastic media: magnetic susceptibility, ...	NF33 - C. Kusina - Spreading behaviour, structures and properties of complex fluids	SM28 - A. Sharma - Effect of polymer architecture on viscoelastic properties of Thermoplastic ...	FP7 - F. Meyer - The use of rheological measurements to study the stability of food and cosmetic ...	IP6 - D. Ferri - Correlation between polymer and powder characteristics and the properties of items ...	LA3 - C. Dessi - Activity modifies shear-thinning rheology in dilute suspensions of kinesin-driven ...	BE32 - G. Filippone - Self-assembly of nanoparticles in immiscible polymer blends	
17:20	CS34 - R. Massaro - Role of polymer matrix architecture on the rheology and flow induced ...	NF34 - C. Metivier - Natural convection in shear-thinning fluids: velocity and temperature ...	SM29 - E. Van Ruymbeke - Understanding and modelling the viscoelastic properties of ...	FP8 - P. Lopez-Sanchez - Viscoelastic properties of plant polysaccharides impact mechanics and rheology of ...	IP7 - B. Robertson - Computer simulations and experimental studies of extrudate swell in monodisperse ...	LA4 - C. de Loubens - Flow induced by active intestinal mucosa at macro- and micro-scales	BE33 - W. Wong - Constitutive modelling of dispersive polymer blends	
17:40	CS35 - M. Fuchs - Channel flow of a colloidal suspension	NF35 - T. Burghelena - Elastic turbulence in a serpentine micro-channel: onset, development, ...	SM30 - X. Wang - Linear-nonlinear dichotomy of nonlinear rheological behavior in polymer melts filled ...	FP9 - D. Gabriele - A rheological approach to bigel investigation	IP8 - G. Peters - A full model for flow-induced, multi-phase, multi-morphological crystallization of ...		BE34 - S. Caserta - Multilamellar vesicles morphology under flow	
18:00	End							
19:00	Concert (Sorrento Cathedral)				(sponsored by TA Instruments)			
20:00	Conference Dinner (Ristorante 'o Parrocchiano)							

Program Overview – Day 3

Apr 20th	Friday						
08:30	Awards (Sirene)						
09:00	Plenary talk (PL3) - F. MacKintosh - Mechanical phase transitions and the rheology of stiff polymers (Sirene)						
	Sirene	Ulisse	Tritone	Nettuno 1	Nettuno 2-3	Nettuno 4	Nettuno 5-6
10:00	CS36 - R. Angelini - Multi-responsive soft microgels: phase behaviour and rheology	NF36 - C. Ligoure - Fracture propagation in polymeric transient networks	SM31 - T. Inoue - Viscoelastic properties of semiflexible polymer solutions	FP10 - M. Stading - Nano-rheometry for food oral processing	IP9 - C. Lee - Stability analysis of isothermal and non-isothermal viscoelastic film casting processes	LA5 - D. Antonio - Biological and bio-inspired motility at microscopic scales: locomotion by shape control	EM1 - P. Bohr - Mono- and biconical geometries in rheometers: exact solution for the flow field ...
10:20	CS37 - M. Mattiello - Rheology of hydrophobically modified soft colloids in water		SM32 - M. Tassieri - Dynamics of semiflexible polymer solutions in the tightly entangled concentration ...	FP11 - L. Howarth - Understanding starch swelling behavior and how it impacts rheology and functional ...	IP10 - C. Balemans - Computational modeling of the selective laser sintering process: viscoelastic flow	LA6 - L. Feriani - Collective dynamics of motile cilia	EM2 - E. Stellamanns - Structural rheology at multiple time and length scales
10:40	CS38 - A. Fanost - How artists achieved tempera paints? Rheology a key tool to understand heritage materials behavior	NF37 - I. Skvortsov - Periodic oscillations in shearing complex liquids	SM33 - A. Bellissimo - Rheology of Polyvinyl alcohol in semi-diluted water solution	FP12 - J. Aguilar - How do pH and acid anion affect thermal gelation of egg yolk?	IP11 - B. O. Conchuir - The structural and rheological properties of micelles in a shear flow	LA7 - K. Martens - Non-linear rheology in a model biological tissue	EM3 - D. Gross - Rheo-NMR, a combination of nuclear magnetic resonance (NMR) and rheometry to ...
11:00	Coffee Break						
11:30	CS39 - R. Sear - Spontaneous stratification in drying films of small and large particles	NF38 - R. Castellani - Coiling instabilities for a power-law fluid: experimental and numerical comparison to the...	SM34 - X. Li - Interactions between rigid rod polysaccharide solutions and saliva	FP13 - Y. Meues - Investigation of the rheological behavior of blended dough systems: examining the interplay...	IP12 - Z. Li - Rheological analysis to understand the mechanism of sewage sludge dewaterability	LA8 - D. Weihs - Rheology of pre-metastatic lung reveals stiffening after in vivo exposure to tumor-derived ...	EM4 - A. Koponen - Experimental Investigation of the flow dynamics and rheology of complex fluids in pipe flow ...
11:50		NF39 - D. Bernardin - Taylor-Couette flow of a shear-thinning fluid	SM35 - T. Shikata - Viscoelastic behaviour of aqueous solution of chemically modified cellulose ethers	FP14 - M. Meerts - Fractional constitutive modelling of the linear and non-linear behaviour of wheat flour...	IP13 - D. Nieto Simavilla - Anisotropic thermal transport in non-linear non-isothermal polymeric flows	LA9 - A. Demiroers - Colloidal shuttles for programmable cargo delivery	EM5 - M. Grosso - Data driven calibration of in line viscosity sensors
12:10	CS40 - Z. Varga - Modeling a hydrodynamic instability in freely settling colloidal gels	NF40 - J. Giacomini - Thermodynamic instability of polymeric liquids in large-amplitude oscillatory shear flow	SM36 - V. Kulichikhin - Rheological and hydrodynamic properties of solutions of ternary copolymers based on ...	FP15 - I. Sousa - Yoghurt as a nutritional ingredient in bakery foods Impact on rheology characteristics of the wheat ...	IP14 - M. Naccache - Exchange flow of yield stress materials in vertical tubes	LA10 - G. Zanchetta - Poised between order and disorder: stress and birefringence relaxation in sheared ...	EM6 - H. Dakhil - Measuring the adhesion limit of cells with a narrow-gap rotational rheometer
12:30	CS41 - C. Negrão - A constitutive model for reversible structured materials	NF41 - H. Wilson - Channel flow instabilities in shear-thinning viscoelastic fluids	SM37 - D. Read - Redrawing the Voigt diagram for binary polymer blends	FP16 - S. Costanzo - Aging and Rheology of Gluten Doughs	IP15 - M. Gahleitner - Gelation phenomena in polypropylene and polyethylene as caused by phase ...	LA11 - M. Nicodemi - Polymer physics of chromosome 3D organisation	EM7 - M. Bouzid - Computing the linear viscoelastic properties of soft gels using an Optimally Windowed Chirp protocol
12:50	Lunch Break						
14:20	CS42 - T. Ridley - Computer simulations of packed soft colloids	NF42 - M. Davoodi - Delay of symmetry-breaking instability in cross-slot geometries using a passive flow- ...	CS52 - W. Chèvremont - Rheology of suspension and particles interactions	FP17 - B. Eral - Biodegradable microfluidic microparticles for simultaneous detection of counterfeit ...	IP16 - G. Mårtensson - Filament breakup and satellite formation in the jetting of highly viscous dense suspensions for ...	LA12 - T. Voigtmann - Theoretical rheology of activebrownian particles	EM8 - G. McKinley - Optimal Fourier Transform Rheometry for Probing Oscillatory Rheology of Complex Fluids ...
14:40	CS43 - M. Leocmach - Gelation as condensation frustrated by hydrodynamics and mechanical ...	NF43 - H. Barlow - Instability of pressure driven channel flows of shear-thinning viscoelastic fluids	CS53 - R. Martone - Effect of the Soil Organic Carbon on the rheology of natural slurries	FP18 - A. Raymundo - Evaluation of the fermentation and aging process of a traditional Eastern fermented product ...	IP17 - G. Baeza - The reinforcement effect in well-defined segmented copolymers: counting the topological ...	LA13 - E. Herrera Valencia - Simultaneous pulsatile and vibratile flow of a human blood with cholesterol: analytical ...	
15:00	CS44 - X. Zhang - Wall slip under unconfined conditions	NF44 - M. Bechert - A combined experimental and theoretical study on draw resonance in polymer melt ...	CS54 - V. Calabrese - Surfactant controlled zwitterionic cellulose nanofibrils dispersions	FP19 - M. Roulet - Mixtures of soft colloids: study of the viscosity of protein-stabilised emulsions	IP18 - C. McIlroy - Semi-Crystalline Polymers in Additive Manufacturing	LA14 - A. Undieh - Characterizing the shear rheology of live endothelial cell monolayers	EM9 - E. Reichel - Electrical breakup rheometry of biofluids in oil submersion
15:20	CS45 - D. Truzzolillo - The glass transition of soft colloids	NF45 - H. Suzuki - Flow Characteristics of Visco-elastic Fluids Injected from a Nozzle	CS55 - S. Gstoehl - Four-dimensional characterisation of microstructure and rheology in suspension flow	FP20 - L. Lanotte - Mechanisms of drying-induced particle formation in mixtures of dairy proteins: a multiscale approach	IP19 - P. Olmsted - Fused deposition modeling with amorphous (glassy) polymers	LA15 - P. Boukany - Rheological response of cellular membranes in pulsed electric fields	EM10 - J. Van Aeken - A new filament stretching device and the exploration of its capabilities and complementarity ...
15:40	CS46 - V. Mahajan - Rheology of non-spherical granular suspensions	NF46 - R. Sayag - Instability of non-Newtonian extensional flows	CS56 - G. Natale - Orientation dynamics of dilute graphene suspensions: dichroism and modeling	FP21 - C. Leverrier - Modelling the viscosity of soft plant particles suspensions	IP20 - M. Yamaguchi - Rheological properties at non-isothermal melt-stretching process and its control ...	LA16 - G. Pesce - Investigation of red blood cell membrane deformability during aging	EM11 - S. Coppola - "Stretching" the operating boundaries of SER: extensional characterization of branched ...
16:00	Coffee Break						
16:30	CS47 - L. Gury - Can soft colloids jam? A comparison between polyelectrolyte microgels and star ...	NF47 - M. Zatloukal - Effect of die exit stress state, Deborah number, uniaxial and planar extensional rheology on ...	CS57 - R. Lapasin - Aging and rheology of salt-free aqueous Laponite dispersions	FP22 - J. Engmann - Rheological design spaces for foods, beverages and skin care products	IP21 - F. Baldi - Capillary flow of HDPE melts filled with lamellar rigid micro-particles	LA17 - C. Wagner - 3-D tomography of blood flow	EM12 - Z. Stary - On the role of the initial sample geometry in the extensional behaviour of a LDPE melt
16:50	CS48 - V. Trappe - Hallmarks of local intermittent relaxation events in the creep behavior of a colloidal gel	NF48 - S. Mirzaagha - Physical stability of structured fluids containing air bubbles	CS58 - R. Tanner - A Quest for a model of non-colloidal suspensions		IP22 - F. Briatico Vangosa - Effects of mold surface treatment on flow behavior and flash formation in ...	LA18 - U. Windberger - The Newtonian behavior of whole blood in dromedary camels	EM13 - P. Rohlmann - Some experimental pitfalls in measuring viscosity of Ionic Liquids
17:10	CS49 - G. Colombo - High speed confocal microscopy of sheared colloidal gels	NF49 - A. Shen - Inertioelastic flow instability at a stagnation point	CS59 - K. Shahriyar - Effect of confinement in the field-induced aggregation of magnetorheological ...	FP23 - P. Fuhrmann - Clustering of oil droplets in o/w emulsions: methodologies to control cluster size ...	IP23 - R. Colby - Shear-induced conformational changes of flexible and semi-rigid engineering thermoplastics ...	LA19 - F. Lamer - LAOStress studies of fibrin clots: The role of incipient clot microstructure in the nonlinear ...	EM14 - D. Vlassopoulos - First and second normal stress differences in polymer fluids
17:30	CS50 - G. Petekidis - Yielding mechanisms and internal relaxations in sheared attractive glasses	NF50 - M. Doi - Onsager principle in viscoelastic flows	CS60 - M. Rosti - Numerical study of suspensions of deformable particles	FP24 - J. Zhang - Bulk and interfacial rheology oil-in-water emulsions stabilised with different types of sugar ...	IP24 - J. Ruiz-Franco - Crystallization of star polymers under shear flow	LA20 - S. Varchanis - Identification of the viscoelastic properties of human blood plasma	EM15 - T. Prenville - Partitioned plate arrangement: a rheological tool to characterize reactive polymers
17:50	CS51 - R. Pastore - Dense vesicle suspensions: relaxation processes and dynamic heterogeneities	NF51 - S. Formenti - Jetting of weakly viscoelastic fluids: a study on polymer degradation in ROER ...	CS61 - P. Carreau - Rheological behavior of cellulose nanocrystals (CNCs) in molten polymers	FP25 - M. Kristiawan - Bolus rheology during chewing of high protein extruded snack from pea flour	IP25 - R. Pantani - Mutual effects of flow and crystallization: analysis of morphology development and ...	LA21 - G. Tomaiuolo - The mechanisms governing red blood cell aggregation. Implications for blood ...	EM16 - J. Laeuger - On the use of a new Shear-Induced Polarized Light Imaging (SIPU) technique
18:10	Closing Ceremony						
18:30	End						

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Wednesday Morning

Symposium PL

Plenary Lectures

Wednesday 9:00 Sirene

PL1

Flow of dense suspensions: protocols to prevent jamming

Michael E. Cates

DAMTP, University of Cambridge, Cambridge, United Kingdom

The flow of very dense suspensions shows problematic features such as discontinuous shear-thickening which can clog processing equipment. Such features are increasingly understood in terms of a (stress-dependent) contact friction between suspended particles. This understanding explains the success of an empirical formulation strategy for increasing flowability by use of so-called 'emulsifiers'. It also suggests a second strategy based on modifying the process flow rather than the formulation, which is to add a vibrational component that stops frictional contacts from building up. Numerical simulations show this to be effective only if the vibration is transverse to the main flow rather than along it. The behavior is partly explicable using the concept of an absorbing state transition created by the vibratory component which is weakly perturbed by the main flow.

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Wednesday 10:00 Sirene

CS1

Rheology of CaCO₃ paste: the solution's physico-chemical role

Teresa Liberto¹, Marie Le Merrer², Catherine Barentin³, Maurizio Bellotto⁴, Jean Colombani⁵, and Sébastien Manneville⁶

¹*Institut Lumière Matière, Université Claude Bernard Lyon 1, Villeurbanne 69622, France;* ²*Institut Lumière Matière, CNRS, Univ. Lyon 1, Villeurbanne 69622, France;* ³*Physics department, Institut of light and matter, Villeurbanne 69622, France;* ⁴*Dipartimento di chimica, materiali ed ingegneria chimica, Politecnico di Milano, Milano, Italy;* ⁵*Institut Lumière Matière, Université Claude Bernard Lyon 1, Villeurbanne, France;* ⁶*Physics, Ens de Lyon, Lyon, France*

Calcite paste exhibits a typical colloidal gel behavior, with an elastic regime and a clear yield strain above which it enters a plastic regime. In a previous study, we characterized the elastic domain of pure calcite suspensions for a wide range of volume concentrations and investigated the relation between microstructure and macroscopic behavior [1]. Going further, the purpose of this study is to control the mechanical properties of calcite paste, investigating the role and origin of the interaction forces that occur between CaCO₃ particles. In order to understand the physical and chemical mechanisms that drive the surface modifications, a wide range of ionic strength, pH and ionic species are analyzed, adding Ca(OH)₂, CaCl₂, NaCl and HCl. These broad ranges are tested to reach the best conditions in term of elasticity and yielding of the paste, in comparison with the mechanical properties of pure calcite suspension [1]. A complete rheological study is made to determine the role of DLVO interaction on the fractal structure through these ranges of parameters. In particular, we characterize both elasticity and flow with respectively plane-plane and helical geometry. We also performed ζ potential measurements on the paste to correlate surface modifications with the rheological response of the CaCO₃ suspensions [2]. We found that several parameters affect the mechanical properties of calcite. In particular, we verified the relevant role of Ca²⁺ and also of others monovalent ions like Na⁺, Ca(OH)⁺ and CaCl⁺. Thanks to this study we are able to control and improve the final properties of the calcite suspension, in particular to increase its ductility.

[1] Liberto, T. et al. (2017). *Soft matter*, 13(10), 2014-2023. [2] Pourchet, S. et al. (2013). *Cement and Concrete Research*, 52, 22-30.

Wednesday 10:20 Sirene

CS2

Rheological properties of injection grouts incorporating nano-silica

Luís Baltazar¹, Fernando M. Henriques¹, Tiago Gouveia¹, and Maria T. Cidade²

¹*Civil Engineering, Faculty of Sciences and Technology, New University of Lisbon, Caparica, Portugal;* ²*Materials Science, Faculty of Sciences and Technology, New University of Lisbon, Caparica, Portugal*

Grout injection into historic masonries is one of the techniques most widely used for seismic strengthening of such walls. Grouts can be seen as suspensions of particles and additives in water which have a considerable fluidity in order to be pumped into masonry inner core. The efficacy of grouts injection depends mainly on their rheological properties, which means that the flow properties of fresh grouts govern the ability of the grout to flow and fill the masonry's voids. However, the variability of voids and cracks within masonry requires an ability to fine design the grout, in order to ensure proper grout penetrability. It is known that most grout's

penetrability problems are due to the grain size characteristics of the solid phase of the grout. Thus, it is believed that the reduced particle size of nano-silica (NS) can contribute to overcome most of grout's penetrability problems. So far, limited research has been carried out to investigate the prospect of using NS to improve the performance of injection grouts, which enhances the importance of a detailed research on the subject. Several rheological properties of natural hydraulic lime based grouts were tested for different dosages of NS (0, 0.5, 1.0, 1.5 and 3.0wt%) by the mass of binder (natural hydraulic lime). Previous studies detected some problems caused by difficulties to disperse the NS during the mix process. Thus, in this work NS coated with silane was used to facilitate the dispersion of particles in aqueous medium. Rheological properties were evaluated with a Bohlin Gemini HRnano rotational rheometer, equipped with parallel-plate geometry. The results showed that the small dosages of NS (up to 1.0 wt.%) led to a slight increase of yield stress values but it had little influence on the plastic viscosity compared to the control sample (without NS). It was also observed that higher NS dosage (>1.5wt%) significantly affects the rheological performance of grouts, which compromises the expected injection capacity.

Wednesday 10:40 Sirene

CS3

Discontinuous shear thickening and stick-slip oscillations tuned by a magnetic field

Georges Bossis¹, Alain Cifre¹, Yan Grasselli², Oumar Gueye¹, and Olga Volkova¹

¹*Institute of Physics of Nice, University of Nice-Sophia Antipolis, Nice 06108, France;* ²*SKEMA Bachelors, Sophia Antipolis 06902, France*

Very concentrated suspensions in water can be obtained thanks to the use of superplasticizer molecules used in cement industry. At high enough volume fraction these suspensions show a discontinuous shear thickening (DST) which happens when the applied stress is large enough to overcome the repulsive force due to the coating polymer. This is for instance the case with calcium carbonate particles but also with iron particles with, in this last case, the possibility to tune the critical shear rate of the DST with a magnetic field [1]. At low shear rate the hydrodynamic stress is negligible, so the amplitude of the magnetic field which triggers the DST transition allows to calculate the threshold force between two particles which is necessary to expel the polymer from the surface. When the magnetic field is decreased the jamming transition occurs at higher shear rate but the critical shear stress strongly decreases. This behavior will be explained on the basis of the different angular dependence of the hydrodynamic and magnetic stresses. Above the critical stress we observe a strong oscillation regime of the shear rate which is partly due to the inertia of the tool [2]. We shall present a model which well reproduces these oscillations and which gives access to the relaxation time of the network of frictional contacts. As the iron particles are conductive, the measurement of the resistance of the suspension can be correlated to the formation of the frictional network of particles during the DST transition and also to the stick slip regime. The experimental results of this new approach will be presented and discussed.

[1] Bossis, G. et al. (2017), Journal of Intelligent Material Systems and Structures, 1045389X17704915. [2] Bossis, G. et al. (2017). Rheologica Acta, 56(5), 415-430.

Wednesday 11:30 Sirene

CS4

Particles in complex formulations: rheology, dynamics and microstructure

Anastasia Papadopoulou, Stavroula Balabani, and Manish K. Tiwari

Mechanical Engineering, University College London, London, United Kingdom

Particle suspensions are encountered in a range of healthcare and industrial formulations as well as biological systems. Rigid spheres suspended in Newtonian media have been studied extensively and their complex rheological behaviour, such as yield stress, shear thinning and shear thickening has been mainly attributed to particle-particle interactions and changes in microstructure. However, in many practical applications particles may vary in surface morphology, shape and porosity while the suspending medium can be non-Newtonian introducing new particle dynamics which are not well understood. In this project, we aim to characterize the microscopic and macroscopic flow properties of dense, non-colloidal particle suspensions in non-aqueous, non-Newtonian matrices in order to understand how differently the non-idealised particles behave compared to rigid spheres. Steady state and oscillatory shear experiments were conducted using smooth glass spheres and rough non-spherical silica particles, commonly used as abrasives or fillers in industrial formulations, suspended in glycerol. Particle concentration ranged from dilute up to the maximum packing fraction for each case. The onset of shear thinning and shear thickening behaviour were investigated at different temperatures. Optical shearing experiments are employed to link the observed rheological behaviour to microstructural changes of the suspensions. Furthermore, the effect of viscoelasticity on suspension behaviour is currently being examined by adding different concentrations of Xanthan gum to the glycerol matrix. Extensional rheometry using a capillary based self-thinning is being conducted in addition to shear rheometry in order to study filament morphology and stringiness. The work forms part of a research programme on addressing manufacturing challenges of non-aqueous paste formulations.

Wednesday 11:50 Sirene

CS5

A new elastoviscoplastic model for highly concentrated suspensions of solid particles

Olivier Ozenda¹, Pierre Saramito², and Guillaume Chambon³

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The mathematical modeling of concentrated suspensions and wet granular flows presents many practical applications, such as risk assessments, landslide predictions for instance. Some viscoplastic models are able to describe stationary flows on simple shear conditions but most of them fail to describe non-stationary or complex flow conditions. We introduce a new texture tensor that represents the local anisotropy of clusters of neighboring particles. This tensor satisfies a new elastoviscoplastic constitutive equation, presented in [1], that combines a viscoplastic model of Drucker-Prager type with a rate-independent viscoelastic evolution. We show that this model unifies the wet granular and the semi-dilute non-colloidal suspensions rheologies. The ability of this model to predict non-stationary flows is explored on a shear reversal experiment and results are compared to available experimental data.

from [2]. Our numerical results show an excellent quantitative agreement with the observations. The microstructure of suspensions is described by the probability $g(\theta)$ for a particle to have a neighboring particle in the θ direction, the so-called pair distribution function. The model is able to predict the depletion angle where this probability is minimum and provides global qualitative agreement with the observation. In conclusion, we propose a new continuous model for suspensions, that is, for the first time, in agreement with experiments for both time-dependent macroscopic measures and observations of microscopic arrangements.

[1] O. Ozenda, P. Saramito, G. Chambon and C. Smutek. submitted, 2017. [2] Blanc, F. et al. (2011). *Journal of Rheology*, 55(4), 835-854.

Wednesday 12:10 Sirene

CS6

Extensional versus shear rheologies for dense suspensions

Ryohei Seto¹ and Giulio G. Giusteri²

¹*OIST, Onna-son, Okinawa 9040495, Japan;* ²*Dipartimento di Matematica e Fisica, Università Cattolica del Sacro Cuore, Brescia, Italy*

Non-trivial rheological behaviors of suspensions stem from flow-induced microstructure and interparticle interactions. The flow-induced microstructure of a suspension may depend on the local flow type and not only on the flow rate. If so, the rheology must have some flow-type dependence. In this way, extensional rheology is a crucial component to explore constitutive modeling for suspensions. However, experimental setups of extensional rheology are substantially different from those employed in shear rheology. In extensional rheology measurements, it is hard to distinguish between bulk properties and interfacial effects and to reach steady flows. Simulations with proper periodic boundary conditions allow us to explore the bulk rheology of suspension models under arbitrary flow types of steady planar flows. We implemented the Kraynik-Reinelt boundary conditions to impose planar extensional flows in a Stokesian Dynamics simulation. In this talk, the role of microstructure in determining the fluid response of dense suspensions under extensional flow and simple shear flow will be discussed.

Wednesday 12:30 Sirene

CS7

Vorticity banding in dense suspensions

Rahul N. Chacko¹, Romain Mari², Michael E. Cates³, and Suzanne M. Fielding¹

¹*Physics, Durham University, Durham, United Kingdom;* ²*LIPhy, Univ. Grenoble Alpes, Grenoble, France;* ³*DAMTP, University of Cambridge, Cambridge, United Kingdom*

Despite decades of research, a model describing the behaviour of suspensions of solid particles in flow has remained elusive, except at low particle concentration [1]. Recently, the importance in dense suspensions of frictional interactions between particles has been appreciated, with minimal microscopic [2] and macroscopic [3] models developed that incorporate these. These models captured for the first time the discontinuous jumps in viscosity with increased imposed shear rate seen in experiments [4], associated with an S-shaped constitutive curve of stress as a function of strain rate. So far, the consequences of this S-shaped constitutive curve have only been explored within calculations that assume a homogeneous flow. In practice, however, such a constitutive curve is known to give rise to flow instabilities that lead to heterogeneous flow, with bands arranged in the vorticity direction [5], consistent with recent experimental work in dense suspensions [4]. In this work, we extend the model of [3] by coupling the flow to concentration and demonstrate within the resulting model the formation of vorticity bands. We also provide the first evidence for vorticity banding in direct particle simulations [6] of dense suspensions. We compare the dynamical behaviours exhibited by our theoretical model to what is seen in experimentally and in our particle simulations, and discuss the implications for the physical mechanisms driving vorticity banding in dense suspensions.

[1] Einstein, A. (1906). *Annalen der Physik*, 324(2), 289-306. [2] Seto, R. et al. (2013). *Physical review letters*, 111(21), 218301. [3] M. Wyart and M. E. Cates, *PRL* 112, 098302 (2014). [4] Hermes, M. et al. (2016). *Journal of Rheology*, 60(5), 905-916. [5] Olmsted, P. D. (2008). *Rheologica Acta*, 47(3), 283-300. [6] Mari, R. et al. (2015). *Physical Review E*, 91(5), 052302.

Symposium NF

Non Newtonian Fluid Mechanics & Flow Instabilities

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Wednesday 10:00 Ulisse

NF1

The behaviours of the elastic capsules in viscoelastic fluid Poiseuille flow with finite inertia

Jingtao Ma, Fangbao Tian, John Young, and Joseph C.S. Lai

School of Engineering and Information Technology, University of New South Wales, Canberra, Australian Capital Territory 2600, Australia

This work presents a three-dimensional numerical study on the behaviours of elastic capsules in the Oldroyd-B viscoelastic fluid Poiseuille flow with finite inertia by employing an immersed boundary-lattice Boltzmann method. The numerical method has been validated by conducting a few typical Oldroyd-B flows: 2D lid-driven cavity, 2D flow past a stationary cylinder, a 2D rigid particle migration in Couette flow, a 3D rigid particle rotation in a shear flow and a 3D elastic capsule deformation in a shear flow. The present results agree well with the data predicted by other numerical method. The present research focuses on the lateral migration and equilibrium position of the elastic capsules in the Oldroyd-B fluid Poiseuille flow with finite inertia, and several interesting phenomena will be discovered.

Wednesday 10:20 Ulisse

NF2

Numerical study of three-dimensional multiphase flows of viscoelastic fluids with the Level-Set methodArtur Sucena¹, Alexandre M. Afonso¹, Manuel A. Alves², and Fernando T. Pinho¹¹*Department of Mechanical engineering, University of Porto, Porto 4200-465, Portugal;* ²*Department of Chemical Engineering, University of Porto, Porto, Portugal*

Abstract This work investigates the behaviour of three-dimensional multiphase flows of rheologically complex fluids. Different values of fluid properties (such as the viscosity and relaxation time) and different geometries were considered in the simulations. **Abstract** The Level-Set method is used to compute the multiphase flows, which was implemented in a Finite Volume Method in-house solver. A mass correction method and a new redistance scheme are used with the Level-set, to improve the precision of the interface representation. **Abstract** The code is initially verified by solving the 2D-droplet transport problem for Newtonian fluids. Subsequently, we consider the same transport problem, a 3D-droplet straight channel flow and a rising bubble system, where the droplet, the continuous fluid or both are non-Newtonian. The rheology of these non-Newtonian fluids are described using the Upper-Convected Maxwell, Oldroyd-B and the Phan-Thien-Tanner models, assessing the different behaviours for each model used. **Abstract** Finally, we study numerically the instabilities in the exit of pipe flow (extrudate swell) of shear thinning fluids. The existence of an helical, supercritical instability was observed experimentally in this type of flow and we replicated it numerically.

Wednesday 10:40 Ulisse

NF3

Dynamics of an elastoviscoplastic drop in a Newtonian medium under shear flowDaulet Izbassarov, Marco E. Rosti, Luca Brandt, and Outi Tammisola*Mechanics, KTH, Stockholm, Sweden*

The dynamics of a single elastoviscoplastic drop in plane shear flow is studied computationally using a finite-difference/level set method. The Saramito model is used for the elastoviscoplastic fluid. The model predicts yield stress behavior, where the unyielded state of the material is described as a Kelvin-Voigt viscoelastic solid and the yielded state as a viscoelastic Oldroyd-B fluid. Full 3D simulations are performed and a full parametric study performed, in particular we vary the Capillary number, the Weissenberg number and the ratio of solvent and total drop viscosity. It is found that these parameters have a significant influence on the drop dynamics. Indeed, numerical simulations predict that droplet deformation significantly increases with Capillary number, Weissenberg number and solvent to the total drop viscosity ratio. Present results are in contrast with the heuristic idea that viscoelasticity in the dispersed phase inhibits deformation. The opposite trend can be explained by the fact that the Kelvin-Voigt viscoelastic model is described by a spring and dashpot mechanical system with the dashpot viscosity directly related to the solvent viscosity ratio and the spring elasticity inversely to the Weissenberg number. The numerical method is first validated for shear driven viscoelastic drop in a Newtonian matrix through comparison with available data in the literature. Then new results on the deformation of elastoviscoplastic drop in Newtonian fluid are presented.

Wednesday 11:30 Ulisse

NF4

Numerical simulations on the dynamics of a spheroid in a viscoelastic liquid in a slit microchannelGaetano D'Avino¹, Francesco Greco¹, Martien A. Hulsen², and Pier Luca Maffettone¹¹*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy;* ²*Eindhoven University of Technology, Eindhoven, The Netherlands*

Particles suspended in viscoelastic liquids are encountered in a huge number of systems. The particle dynamics, when the suspension is subjected to an external flow field, depends on several properties. Among them, particle shape plays a crucial role in determining the particle translational and rotational motion. The most of the works available on particle dynamics in viscoelastic liquids consider spherical inclusions. The few studies on non-spherical particle viscoelastic suspensions have been mainly performed in a simple shear flow field, showing the attainment of preferential equilibrium orientations depending on the applied shear rate. We are unaware of studies on non-spherical particle viscoelastic suspensions in channel flows. In this contribution, we investigate the motion of an inertialess, rigid, spheroidal particle suspended in a viscoelastic fluid under pressure-driven flow between two infinite parallel walls. The wall distance is comparable with the particle characteristic dimension so that confinement effects are relevant. We employ 3D finite element direct numerical simulations with an automatic remeshing algorithm to account for the severe mesh distortion induced by the particle orientation change. The translational and orientational particle dynamics, with specific interest in the migration phenomenon, is investigated by varying the initial particle position and orientation, and the Deborah number.

Wednesday 11:50 Ulisse

NF5

Thermocapillary motion of a Newtonian droplet in a viscoelastic fluid under Stokes flow conditionsPaolo Capobianchi, Marcello Lappa, and Mónica S. N. Oliveira*Mechanical and Aerospace Engineering, university of Strathclyde, Glasgow G1 1XJ, United Kingdom*

The thermocapillary motion of a Newtonian droplet surrounded by a viscoelastic immiscible liquid phase is investigated numerically in the limiting conditions of vanishing small Reynolds and Marangoni numbers and in the absence of buoyant effects. The computational study has been carried out in the framework of a hybrid Level-Set-Volume of Fluid method implemented in the OpenFOAM platform. Initially, a spherical Newtonian droplet is placed in a container filled with a viscoelastic liquid. Subsequently, a thermal gradient is applied by fixing different temperatures on the top and bottom wall of the container so that an interfacial tangential stress imbalance is produced at the interface separating the two immiscible phases. As a result of this gradient, non-equilibrium conditions are attained forcing matrix fluid to move from the higher temperature region to the lower temperature region and the drop to migrate in the opposite direction. According to our results, the droplet migration speed and shape are significantly affected by the viscoelastic nature of the matrix phase. In particular, the migration droplet speed displays a decreasing trend for increasing Deborah number while maintaining constant the viscosity ratio (polymer/total).

Wednesday 12:10 Ulisse

NF6

Transfer of rate-thinning and rate-thickening liquids between separating plates and cavitiesJyun-Ting Wu¹, Marcio S. Carvalho², and Satish Kumar¹¹*Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN 55113, United States;*²*Mechanical Engineering, PUC-Rio, Rio de Janeiro, Brazil*

One promising technology for fabricating low-cost printed electronics on a large scale is roll-to-roll gravure, which involves transfer of inks from microscale cavities to a second surface. Although printing inks containing functional additives usually exhibit non-Newtonian rheological behavior, the influence of ink rheology on liquid transfer is not yet well understood. To address this issue, an axisymmetric model is used to develop fundamental understanding of how ink rheology affects liquid transfer between vertically separating surfaces. Liquids whose rheological behavior is described by Carreau-type models are considered, inertial and gravitational forces are neglected, and the nonlinear governing equations are solved with the Galerkin finite-element method. For liquid transfer between two flat plates, the results reveal that rate-thinning (rate-thickening) rheology leads to reduced (enhanced) viscosities near the less-wettable surface where stronger pressure gradients arise. The reduced (enhanced) viscous forces further assist (hinder) the slip of the moving contact line, allowing more (less) liquid to be transferred from the less-wettable surface to the more-wettable one. For liquid transfer between a flat plate and a trapezoidal cavity, the effect of cavity angle on liquid transfer is investigated first. The amount of liquid transferred to the flat plate is found to increase with a larger cavity angle and this phenomenon is observed for both Newtonian and rate-dependent liquids. In addition, the influence of rate-dependent rheology is found to primarily occur near the flat plate. This behavior is attributed to the presence of the cavity wall, which reduces the interface deformation, the associated capillary pressure gradients, and thus the effect of rate-dependent rheology. As a consequence, rate-thickening (rate-thinning) tends to increase (decrease) the amount of liquid transferred from the cavity.

Wednesday 12:30 Ulisse

NF7

Hydrodynamic mixing of yield stress fluids by gas injectionAli Hojeij, Laurent Jossic, and Albert Magnin*Laboratoire Rhéologie et Procédés, Grenoble-INP, Grenoble, France*

Methanation is a process in which organic and agricultural waste is converted to biogas through anaerobic digestion. In such process, the treated feed is a fluid mixture with high solids content. This leads to very high consistencies and yield stresses which generate complex flow fields with the coexistence of sheared and rigid zones. This mixture is regularly mixed in order to increase biogas production yield. Pneumatic mixing is a promising technology in this field, it consists of injection of pressurized biogas into the mixture through injection pipes which allows the flow of the material and create a convective movement around the pipes. Pneumatic mixing appears to be more economic and "process-friendly" than traditional mechanical mixing, where methanation bacteria could be harmed and thus decreasing the yield. On the other hand, mixing intensity and fluid flow patterns for these yield stress fluids are not yet well understood and controlled. In this context, an experimental pilot reactor setup has been built at Laboratoire Rhéologie et Procédés to reproduce the flow conditions present in the industrial scale reactor and to visualize the flows. The organic substrate is modeled as a yield stress transparent fluid and air is injected under pressure into the reactor tank. This air jet creates at the bottom of the tank an air pocket that periodically grows and shrinks releasing air bubbles into the fluid. These bubbles rise to create a stirring effect. In our study, we focused on the influence of fluid rheology and injection parameters, as well as the geometric configuration of the injection nozzle, on the morphology of the gas pocket. In addition, we studied the mixing generated by the rising bubbles by adapting methods to measure mixing and recirculation times using dyes and particle tracking. It was clear that air flow rate and fluid rheological properties have the greatest effect on fluid flow and bubble dynamics.

Symposium SM**Polymer Solutions & Melts**

Organizers: Yuichi Masubuchi, Angel Moreno and Daniel Read

Wednesday 10:00 Tritone

Keynote SM1

Intrinsically-nonlinear rheometryRandy Ewoldt*Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, United States*

Weakly nonlinear excitations are a fundamental characterization technique used in optics, acoustics, heat transfer, and other fields. Rheometry methods have comparatively lagged in this area, but recent progress has allowed for experimental and theoretical advances with significant implications for microstructure inference and insight. This talk will review our contributions to intrinsically-nonlinear rheometry, also called medium-amplitude oscillatory shear (MAOS). MAOS is the systematic step beyond linear viscoelasticity, a power-series expansion of large-amplitude oscillatory shear (LAOS). If you are comfortable with the two descriptions of small-amplitude oscillatory shear (SAOS), e.g. G' and G'' , then you will quickly gain comfort with the four descriptions of the MAOS shear stress response, e.g. $[e1]$, $[e3]$, $[v1]$, and $[v3]$. As in SAOS and linear viscoelasticity, the four MAOS measures are functions of only frequency, not amplitude. Our theoretical contributions include complete definitions of all four MAOS signals, physical interpretations of these measures, and derivations of universal aspects of their terminal regime signatures. Experimentally, I will discuss best practices for measuring these properties and demonstrate methods of faster data acquisition. Finally, I will describe applications of microstructure inference and constitutive model development for two cases: a supramolecular transient network polymer gel and a microgel suspension. In both cases, new models were developed to explain and fit data that no

prior model could even qualitatively explain. The MAOS signature revealed the discrepancy, leading to new structure-to-rheology understanding.

Wednesday 10:40 Tritone

SM2

Non-linear shear rheology of dendronized polymethacrylate melts studied with the cone-partitioned plate technique

Thomas Schweizer, Daniel Messmer, and A. Dieter Schlüter

Institut für Polymere, ETH Zurich, Zurich, Zurich 8093, Switzerland

Dendronized polymers (DP) fit in the gap between conventional linear polymers and star shaped polymers. By offering two structural parameters, the number of branch points per side chain (viz. the generation) and the degree of polymerization (DOP), the rheological behavior can be tuned in a wide range. By modifying the end groups of each side chain, even a third parameter would be available. In the present study however, the end groups are always tert-butyloxycarbonyl (Boc). A melt of DP is characterized by strong interdigitation between the side groups of neighboring chains. In this study, the effect of different generations and different DOP on the non-linear shear rheology of dendronized polymethacrylate polymers is studied at a temperature 40°C above their glass transition temperature. Due to the strong interdigitation, these melts are prone to high viscosities, pronounced 1st and 2nd normal stress differences and therefore also edge fracture. An MCR502 twin drive rheometer with a 6° cone and the commercial partitioned plate CPP8 is particularly suited for studying such melts. To cover both, the inner partition of 8 mm diameter and part of the outer partition, a sample mass of order 40 mg is sufficient. Each sample was subjected to several step shear rate tests, followed by relaxation, until edge fracture was too severe. The last was checked by comparing the torques of the two measuring motors and by interleaving frequency sweep tests between each two of the step shear rate tests. By increasing the generation at constant DOP of 500, the viscosity showed a transition from the behavior of a conventional linear polymer to a pronounced shear hardening behavior, which is the result of the strong interdigitation.

Wednesday 11:30 Tritone

SM3

Novel flexible polystyrenes show increased tensile strength

Qian Huang¹, Jeppe Madsen¹, Marco Milia¹, Kell Mortensen², and Ole Hassager¹

¹*Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kongens Lyngby DK-2800, Denmark;* ²*Niels Bohr Institute, University of Copenhagen, Copenhagen OE, Denmark*

Atactic polystyrene is one of the most widely used thermoplastics. It is an amorphous material, and below its glass transition temperature (T_g) it is transparent and rather brittle. The ultimate tensile strength for glassy polystyrene is reported to be 20-55MPa [1, 2].

In this work, we present a novel way to process atactic polystyrenes, which increases their tensile strength. We investigated two nearly monodisperse polystyrenes with molecular weights of 100 kg/mol and 285 kg/mol respectively, as well as a commercial polystyrene with weight average molecular weight of 230kg/mol and a polydispersity of 3.7. The polystyrene samples were stretched at different strain rates in a filament stretching rheometer above T_g , and the samples were quenched while at large Hencky strain. We found that when stretched at low rates, the quenched samples were brittle and had a tensile strength around 50 MPa, which corresponds to literature values [1]. However, when stretched at fast rates, the quenched samples were surprisingly flexible, and the measured tensile strength was above 200 MPa. To elucidate the mechanism, the flexible polystyrenes were further characterized by microscopic techniques, by X-ray scattering, and using high-speed imaging. The results were compared with those of non-processed, brittle polystyrenes. Our results indicate that stretching of entanglement strand is the main reason for the observed flexibility and the higher tensile strength. The flexible, transparent polystyrenes with increased tensile strength may have potential applications such as optical fibers. The presented processing method may be used to make stronger polymer fibers in general.

[1] Fried, J. R. (2014). Polymer science and technology. Pearson Education. [2] Jiang, S. et al. (2014). ACS applied materials & interfaces, 6(8), 5918-5923.

Wednesday 11:50 Tritone

SM4

Uniaxial extensional viscosity of Poly(n-alkylstyrene)s

Yumi Matsumiya and Hiroshi Watanabe

Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan

Uniaxial extensional behavior was examined for poly(4-n-alkylstyrene)s (PCmSt; m(=1~4) is a number of carbon in side alkyl group) having almost identical degree of polymerization. Linear viscoelastic data revealed that glass relaxation was relatively accelerated with respect to chain relaxation for larger m. Normalized steady state elongational viscosity η_E/η_{E0} for PC1St exhibited monotonic thinning with increasing strain rate. η_E/η_{E0} exhibited hardening followed by thinning for other samples, and η_E/η_{E0} increased with increasing m. This could be attributed to side alkyl chain, which may behave like solvent to suppress reduction of monomeric friction (and possibly to reduce the effect of glass relaxation).

Wednesday 12:10 Tritone

SM5

Assessing the monomeric friction reduction mechanism with monodispersed linear Polystyrene blends

Taisir Shahid¹, Christian Clasen², Filip Oosterlinck³, and Evelyne Van Ruymbeke¹

¹*Institute of Condensed Matter and Nanosciences, University Catholique de Louvain, Louvain-la-Neuve, Walloon Brabant 1348, Belgium;* ²*Department of Chemical Engineering, KU, Leuven, Leuven, Belgium;* ³*Materials Science Center, DSM Research, Geleen, The Netherlands*

The qualitative difference between polymer melts and solutions in elongational flow has baffled researchers across the globe. While polymer melts show a monotonic thinning behavior for all applied strain rates, polymer solutions exhibit an initial thinning behavior followed by a strong thickening trend, making it very difficult to predict these two phenomena under one common scheme. The most recent mechanism proposed to explain both observations is the alignment-induced friction reduction concept, which seems to be widely accepted by now and can describe both polymer melts and solution in a quantitative manner. The aim of this work is to assess this concept experimentally with a series of polymer blends where a long chain polystyrene is diluted in a series of short polystyrene oligomers of different molecular weights, so that the solvent oligomer chains themselves cover an entanglement range of unentangled, barely entangled and well-entangled. Depending on the degree of entanglements of the oligomeric solvent, one would expect that the nematic interaction between the solvent and the polymer would change and therefore alter the fast flow dynamics of the blends. With longer solvent molecules a higher nematic interaction between the long polymer and solvent oligomer is expected, which would cause reduction in monomeric friction and should ultimately result in a lowering of the strain hardening phenomenon. But surprisingly, the experimental results show that all polystyrene blends behave similarly i.e. they have the same steady state elongational viscosity when measured at same temperature distance from their T_g . This observation leads us to the hypothesis that the polymer-oligomer and polymer-polymer nematic interaction is the same as long as the length of the 'solvent' molecules is more than the size of a Kuhn segment. Since this experimental observation is contrary to the expected behavior for a flow-induced monomeric friction reduction mechanism, it raises several new interesting questions.

Wednesday 12:30 Tritone

SM6

The effect of extensional flow on shear viscosity

Richard Hodgkinson¹, Jonathan R. Howse², and William B. Zimmerman²

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Rheology is usually concerned with characterising flows under pure shear, or occasionally, pure extension. This is in contrast to real world flows in extruder dies, for example, which feature mixed kinematics but also significant scientific and commercial importance in their understanding. We postulate here that for an example shear thinning system, shear viscosity is not only a function of shear rate, but both shear and extension rate. Relative straining directions are also important. This builds directly on from findings in a key set of molecular dynamics simulations [1] as well as phenomena such as molecular alignment under extensional flow and the anisotropic viscosities of liquid crystals [2]. This has important consequences on factors such as velocity profiles for fluids undergoing extension (as seen in [3]). We describe and perform an experiment that is capable of measuring both shear stresses and rates, not at the wall where the extension rate is zero [4] but in-situ and at defined locations within the core of an extensional flow field. The experiment is first verified using a Newtonian system, following which a model high molecular weight polyethylene oxide solution is then studied. Results are presented for both systems.

[1] Evans, M. W., & Heyes, D. M. (1990). *Molecular Physics*, 69(2), 241-263. [2] Sengupta, A. et al. (2014). *Liquid Crystals Reviews*, 2(2), 73-110. [3] Trebbin, M. et al. (2013). *Proceedings of the National Academy of Sciences*, 110(17), 6706-6711. [4] Cogswell, F. N. (1978). *Journal of Non-Newtonian Fluid Mechanics*, 4(1-2), 23-38.

Symposium MN

Micro, Nano Fluidics & Microrheology

Organizers: Nikolai Denkov, Sehyun Shin and Manlio Tassieri

Wednesday 10:00 Nettuno 1

MN1

Flow of foam in model porous media

Alexis Mauray¹, Max Chabert², and Hugues Bodiguel¹

¹*LRP, CNRS, Univ. Grenoble-Alpes, Grenoble INP, Grenoble, France;* ²*Solvay, Singapore, Singapore*

We investigate the flow of foam in transparent model of porous media made using microfluidics. Foam consist in a dispersion of bubbles in a surfactant solution, that are obtained by injecting both phase simultaneously in the micromodel at high flow rate. The foam is then stored and injected at a constant flow rate in the same device. This protocol leads to bubble that are about the pore size. Their volume fraction is varied by controlling the relative gas flow rate, between 0.2 and 0.9. We simultaneously measure the pressure drop and determine by direct observation bubble displacement. The apparent viscosity is more than 10^3 times that of the water for a capillary number (Ca) of 10^{-6} . It decreases when Ca is increased, following a power-law between -0.7 and -1, depending on the relative gas flow rate. These observations are in very similar to measurements in real rocks. The high apparent viscosity and the rather important shear-thinning behavior has been interpreted as the consequence of Bretherton law and the trapping of the gas phase in a fraction of the pores. However, by analyzing the movies, we show that though preferential paths for the gas phase are observed at low and intermediate gas flow rate, the flow is more and more homogeneous when increasing the relative gas flow rate.

This unexpected result indicates that additional mechanisms are to be considered to account for the global pressure drop. In order to investigate this issue, we studied the motion of bubble trains in straight and wavy channels. We show that the pressure drop in straight ones is well accounted by Bretherton law. In contrast, in the channels of varying cross-section, it deviates from power law behavior and exhibit a plateau below $Ca = 2 \cdot 10^4$. Correlatively, the motion of the gas phase is intermittent, with long period where the bubbles remains immobile. Using the phenomenological law found in wavy channels, we propose a model which accounts for the apparent viscosity measured in the model porous medium.

Wednesday 10:20 Nettuno 1

MN2

Flow instability and mixing in dilute polymer solution in a gear-shaped microchannel

Sun Ok Hong¹, Ki-Su Park², Dong-Yeong Kim², Sung Sik Lee³, Chang-Soo Lee², and Ju Min Kim¹

¹Ajou University, Suwon, Republic of Korea; ²Chungnam National University, Daejeon, Republic of Korea; ³ETH Zurich, Zurich, Switzerland

Flow instability in viscoelastic fluid has been an interesting research topic and is also significant in a wide range of industrial application such as film blowing, extrusion, and coating process. More recently, the flow instability of viscoelastic fluid in microfluidic device has been investigated by many researchers because it can be used to enhance the mixing, which is inherently difficult due to the laminar flow characteristics in small-scale flow. It is well known that, in a serpentine channel, the hoop stress generated along the curved streamline causes the flow instability in viscoelastic flow, however, which has been mainly limited to low-Reynolds-number conditions. Recently, our group demonstrated that the vortices in the side-well arrays of a straight channel are severely irregular and chaotic in low-viscosity dilute polymer solution when both inertia and elasticity are relevant, which was utilized to enhance the mixing. In this work, we demonstrate a novel micromixing method by combining the conventional serpentine-channel and the side-wells, which is term as 'gear-shaped micromixer'. The basic principles of the gear-shaped micromixer will be elucidated, and we will thoroughly analyze the micromixer with various visualization techniques and pressure difference measurement. We will show that this novel micromixing technique has very high mixing efficiency for a wide range of flow rates in contrast to the conventional serpentine channel. Further, we demonstrate the synthesis of monodisperse silica colloidal particles with the current micromixing method.

Wednesday 10:40 Nettuno 1

MN3

Realization of multiple-line particle focusing under viscoelastic flow

Sei Hyun Yang¹, Doo Jin Lee², Jae Ryoun Youn¹, and Young Seok Song³

¹Department of Materials Science and Engineering, Seoul National University, Seoul 08826, Republic of Korea;

²Ceramic Fiber and Composite Materials Center, Korea Institution of Ceramic Engineering and Technology, Jinju 52851, Republic of Korea; ³Department of Fiber System Engineering, Dankook University, Gyeonggi 16890, Republic of Korea

Particles in a viscoelastic fluid are typically focused at the center and four corners of a rectangular channel due to the combination of fluid elasticity and inertia forces. In this study, we observe the transition between single-line and multiple-line particle focusing in a microfluidic device induced by the synergetic effect of inertia and viscoelasticity. The elastic and inertial forces acting on suspended particles are manipulated by controlling the concentration of dilute polymer solution and the flow rate of a fluid. The finding shows that the confinement effects determined by the channel aspect ratio and the inlet geometry lead to the multiple-line focusing of particles in the microfluidic channel due to the fluid elasticity and hydrodynamic behavior of the fluid. A microfluidic channel with high channel aspect ratio possesses broad minimal region of the elastic force across the channel, which generates a wide particle focusing band rather than a single particle focusing at the center. The multiple-line particle focusing occurs as the inertial force outweighs the elastic force, resulting in the particle migration towards the channel sidewalls.

Wednesday 11:30 Nettuno 1

MN4

A novel microfluidic technique to measure interfacial tension of emulsions

Rosa D'Apolito¹, Antonio Perazzo², Mariapia D'Antuono¹, Valentina Preziosi¹, Giovanna Tomaiuolo¹, Reinhard Miller³, and Stefano Guido¹

¹ Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy; ²Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ 08544, United States; ³Max-Planck-Institut für Kolloid und Grenzflächenforschung, Potsdam, Germany

A novel microfluidic device for the accurate measurement of surfactant dependent interfacial tension (IFT) between two immiscible liquids is developed. In our approach, IFT of a water-in-oil emulsion at different surfactant concentrations is obtained from a quantitative analysis of droplet deformation in shear flow. The validity of our microfluidic tensiometry is then demonstrated in a broad range of interfacial tensions and the identification of the surfactant critical micellar concentration (CMC) is obtained. Our results are also compared with experimental measurements obtained by the pendant drop technique in the range of concentrations allowed by the classical instrument, and a very good agreement is found. At high surfactant concentrations, when the common methods tend to fail, our microfluidic setup is still working, providing a powerful tool to measure the interfacial tension of complex systems.

Wednesday 11:50 Nettuno 1

MN5

Determination of the mechanical properties of soft particles through a non-invasive microfluidic techniqueMassimiliano M. Villone¹, Janine K. Nunes², Howard A. Stone², and Pier Luca Maffettone¹¹*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy;* ²*Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ 08544, United States*

Suspensions carrying deformable inclusions are ubiquitous in nature, scientific, and industrial applications. In particular, elastic particles are a good model for microgel beads, swollen starch granules, and cells. High-throughput characterization of the mechanical properties of soft particles would be, then, of great interest. Recently, a non-invasive microfluidic technique has been developed for the measurement of the interfacial tension between two immiscible liquids [1]. We have adapted such technique to the case of soft solid beads, in such a way as to provide a non-invasive microfluidic technique for the measurement of the mechanical properties of deformable particles. We have designed a cylindrical microfluidic channel with a cross section reduction in which initially spherical soft beads are made to flow suspended in a Newtonian carrier. By recording in real time the deformation of a particle as it goes through the constriction, it is possible to get a measure of its elastic modulus through of a theoretically derived-correlation. We provide both experimental and numerical validation of our design.

[1] Hudson, S. D. et al. (2005). Applied Physics Letters, 87(8), 081905.

Wednesday 12:10 Nettuno 1

MN6

Drop deformation in microfluidics for viscosity measurementsEstelle André¹, Nicolas Pannacci¹, Christine Dalmazzone¹, and Annie Colin²¹*Applied Chemistry and Physical Chemistry, IFP Energies nouvelles, Rueil-Malmaison 92500, France;* ²*CBI, ESPCI, Paris, France*

Measurement of solution's viscosity is important for a variety of areas including industrial, chemical and biological applications. Numerous single-phase microfluidic viscometers have been reported in the literature. However droplet-based microfluidics allow the use of much smaller volumes and especially the possibility to handle and analyze multiple samples at the same time and in a high throughput manner. The aim of our work is thus to develop a microfluidic device using droplets that can perform high-throughput measurements of viscosity. To achieve this objective, we chose to study the phenomenon of deformation and relaxation of a droplet at the exit of a microfluidic constriction. As the droplet exits the constriction, it experiences a deformation in the direction perpendicular to the flow. This deformation reaches a maximum before the droplet relaxes to a rest spherical shape. The viscosity of the droplet phase can theoretically be extracted from two parameters, the droplet relaxation time and the droplet maximum deformation. The latter is experimentally easier to measure and is thus the one we chose to study. Assuming the dimensionless numbers controlling the maximum deformation of the droplet are the capillary number, a geometrical number and the viscosity ratio, no overall scaling relationship was found when the droplet is confined. However, when the droplet is unconfined, all data collapse on a master curve. A measurement of the droplet viscosity can thus be achieved. The calibration of the power law was achieved on silicone oil droplets in water-glycerol mixtures without surfactant varying the viscosity of the two phases for viscosity ratios between 1 and 10 and droplet phase viscosities between 20 and 100 mPa.s. The scaling was found to be also valid for systems with Newtonian polymers and surfactants.

Wednesday 12:30 Nettuno 1

MN7

Microfluidic in situ mechanical testing of flexible particlesAnke Lindner¹, Camille Duprat², Jean Cappello¹, Charles Duchêne¹, and Olivia Du Roure¹¹*PMMH, ESPCI Paris, Paris, France;* ²*LadHyX, Ecole polytechnique, Palaiseau, France*

The control and knowledge of the mechanical properties of microscopic particles, as vesicles, red blood cells, aggregates or micro-fabricated objects, is critical in a number of applications, but no simple in situ method exists to determine these properties. We propose to use an in-situ method that directly measures the mechanical properties of such particles inside microfluidic channels. To do so we measure the deformation of different types of model particles (photo-polymerized gels, protein aggregates) of various shapes (beam, disc or random) under controlled flow forcing. Taking into account viscous drag as well as applied pressure and wall friction, we gain direct access to the Young's modulus of the materials themselves [1]. This technique can in the future also be extended to investigate more complex biological particles as vesicles and blood cells.

[1] Duprat, C. et al. (2015). Lab on a Chip, 15(1), 244-252.

Symposium SG

Solids, Glasses, & Granular Materials

Organizers: Philippe Coussot, Joe Goddard and Luigi Grassia

Wednesday 10:00 Nettuno 2-3

SG1

New understanding of collective modes and thermodynamics of the liquid stateKostya Trachenko*Queen Mary University of London, London E1 4NS, United Kingdom*

A theory of liquids and liquid-glass transition requires understanding most basic thermodynamics properties of the liquid state such as energy and heat capacity. This has turned out to be a long-standing problem in physics. Landau & Lifshitz textbook states that no general formulas can be derived for liquid thermodynamic functions because the interactions are both strong and system-specific. Phrased differently, liquids have no small parameter. Recent experimental and theoretical results open a new way to understand liquid thermodynamics on the basis of collective modes (phonons) as is done in the solid state theory. There are important differences between phonons in solids and liquids, and we have recently started to understand and quantify this difference. I will review collective modes in liquids including high-frequency solid-like transverse modes and will discuss how a gap in the reciprocal space emerges and develops in their spectrum. This reduces the number of phonons with temperature, consistent with the experimental decrease of constant-volume specific heat with temperature [1]. I will discuss the implication of the above theory for the liquid-glass transition and the change of heat capacity at T_g . I will also mention how this picture can be extended above the critical point where the recently proposed Frenkel line separates liquid-like and gas-like states of supercritical dynamics

[1]. Trachenko, K., & Brazhkin, V. V. (2015). Reports on Progress in Physics, 79(1), 016502.

Wednesday 10:20 Nettuno 2-3

SG2

Shear-induced structural rearrangement in jammed suspensions of soft particle glassesRoger T. Bonnecaze¹, Fardin Khabaz¹, Tianfei Liu¹, and Michel Cloitre²¹*McKetta Department of Chemical Engineering, The University of Texas at Austin, Austin, TX 78712, United States;*²*Laboratoire Matière Molle et Chimie, ESPCI ParisTech, Paris 75005, France*

The microstructure and steady shear rheology of highly concentrated, jammed suspensions of soft particles are shown to depend on polydispersity and shear rate from computational simulations. Rich behavior is observed depending on the degree of polydispersity and the shear rate. Glassy suspensions with a low degree of polydispersity evolve to face-centered cubic (FCC) and hexagonal close-packed (HCP) structures at low and high shear rates, respectively. The structural rearrangement occurs over several units of strain and reduces the shear stress and elastic energy. Suspensions with a higher degree of polydispersity exhibit a microstructural transition from a glass to a layered-like structure for sufficiently high shear rates. In this case the soft particles initially rearrange themselves in the flow-vorticity plane, and then layers parallel to the velocity-vorticity plane are formed. The rearrangement of particles in the flow-vorticity plane occurs after an induction strain (or time). The induction strain decays exponentially with shear rate and shows a universal trend that depends only on polydispersity. A generic dynamical state diagram is found that depends on the polydispersity and the ratio of viscous to elastic forces due to shear. The behavior in oscillatory shear flows is also explored. SPGs remain glassy for maximum oscillatory strains less than the yield strain of the material. For maximum strains greater than the yield strain, microstructural and rheological transitions occur for SPGs. The state diagram in the oscillatory shear flow is found to be in close but not exact agreement with that in the steady shear diagram. The state diagrams in steady and oscillatory shear can explain the very different experimental observation on the microstructure of glassy suspensions and propose polydispersity index as an essential parameter that determines the states of a suspension.

Wednesday 10:40 Nettuno 2-3

SG3

The delocalization transition in a colloidal glassMarkus Gruber¹, Gustavo Abade¹, Matthias Fuchs¹, and Antonio M. Puertas²¹*University of Konstanz, Konstanz, Germany;* ²*Universidad de Almería, Almería, Spain*

The motion of probe particles provides important insights into the local transport processes and structural dynamics of dense colloidal dispersions. While passive particles probe the linear response of the system, nonlinear phenomena can be studied by applying an external force on the colloidal probe. We study the microscopic analogon of shear melting, where the force on the probe is so strong that it can break out of its cage and delocalize [1]. The crossover from a localized to a delocalized behavior of the probe particle at a critical force will be called the delocalization transition. Our model system is a spherical probe particle subject to a constant external force in a colloidal suspension of hard spheres around the glass transition. In order to calculate the self-part of the van-Hove-function for the probe particles, which describes the statistical dynamics of the probe, we use a refined mode-coupling theory (MCT) approach for the self-intermediate scattering function, supported by molecular dynamics computer simulations. We find that the critical force is strongly connected to the strength of the local cages. Furthermore, the van-Hove-function exhibits an exponential tail in force direction, which increases in weight and correlation length when approaching the critical force. This indicates strong dynamical fluctuations, which will dominate measurements of active microrheology.

[1] Gruber, M. et al. (2016). Physical Review E, 94(4), 042602.

Wednesday 11:30 Nettuno 2-3

SG4

Shear thinning in glassy liquidsAkira Furukawa*Institute of Industrial Science, University of Tokyo, Meguro-ku, Tokyo 161-0033, Japan*

We propose a simple mechanism for describing the onset of shear-thinning in a high density glassy liquid [1]. In a shear flow, along the compression axis, the overlap between neighboring particles is more enhanced than that at equilibrium, meaning that the "effective" size is reduced along this axis. On the other hand, along the extension axis perpendicular to the compression axis, the average structural configurations are stretched, but it does not indicate the expansion of the "effective" size itself. This asymmetric shear flow effect for particles results in a small reduction of the "effective" density. Because, in glass-forming liquids, the structural relaxation time τ_α strongly depends on the density ρ , even a very small reduction of the effective density should lead to a significant decrease of the relaxation time under shear flow. We predict that the crossover shear rate from Newtonian to non-Newtonian flow behaviors is given by $[\rho(\partial\tau_\alpha/\partial\rho)]^{-1}$, which can be much smaller than $1/\tau_\alpha$ near the glass transition point [1, 2]. It is shown that this prediction is consistent with the results of molecular dynamics simulations.

[1] Furukawa, A. (2017). Physical Review E, 95(1), 012613. [2] Furukawa, A. et al. (2009). Physical review letters, 102(1), 016001.

Wednesday 11:50 Nettuno 2-3

SG5

Microscopic dynamics during the yielding of a dense glass of soft spheresStefano Aime, Laurence Ramos, and Luca Cipelletti*CNRS & Université de Montpellier, Laboratoire Charles Coulomb, Montpellier, France*

We study the fatigue of a soft glass submitted to repeated oscillatory shear deformation using a unique instrument that simultaneously probes the mechanical response of the sample and its microscopic dynamics. The soft glass, a dense packing of microgel particles, exhibits at rest a spontaneous ballistic dynamics, characterized by compressed exponential relaxations, in line with rearrangements being due to the relaxation of internal stresses in a soft solid. Oscillatory shear measurements show a characteristic single step yielding process. To better understand the microscopic origin of yielding, we couple dynamic light scattering to shear rheology and track both the reversible non affine dynamics and the decay of higher order correlation echoes, up to 500 cycles. Several regimes are found by increasing the shear amplitude. Unperturbed spontaneous solid-like relaxation is measured in the linear regime. In this regime, the non-affinities are fullyreversible and originate presumably from spatial fluctuations of the sample elastic modulus. By contrast, the non-affinities become partially irreversible in the non-linear regime and stem from plastic rearrangements. At the onset of non-linearity ($\gamma \sim 6\%$), we find that dynamics accelerates sharply but still exhibit a solid-like compressed exponential relaxation. In the fully fluidized regime ($\gamma > 30\%$), the microscopic dynamics is however qualitatively different and exhibits a stretched exponential decay, characteristic of a supercooled liquid. Interestingly, we find over a relatively broad range of strain amplitude, which macroscopically corresponds to the regime of a prominent loss peak in the rheology data, the coexistence of a fast liquid-like mode and a slower solid-like mode. Overall, our experimental results that combine macroscopic and microscopic data provide a rational scenario for the fatigue yielding of a heterogeneous soft solid.

Wednesday 12:10 Nettuno 2-3

SG6

The colloidal glass transition: relaxing into arrestRoseanna N. Zia¹ and Jialun Wang²

¹Chemical Engineering, Stanford University, Stanford, CA 94305, United States; ²Chemical & Biomolecular Engineering, Cornell University, Ithaca, NY 14853, United States

We study via large-scale dynamic simulation the colloidal glass transition and subsequent structural relaxation, utilizing controlled jumps from the liquid state into the putative glass region. We execute such volume-fraction jumps with a range of quench depths and quench rates, where particle size increases at constant system volume. Here we focus on post-jump particle dynamics, where we implement the protocols of the McKenna-Kovacs signature experiments (intrinsic iso-volume-fraction) to study the approach to a stationary state. The results are compared with light scattering and rheology experiments and show qualitative agreement. The system takes a finite time to reach a metastable intransient state at the widely-accepted colloidal glass transition point, volume fraction $\phi = 0.58$, challenging prior assertions that particle dynamics vanish at the glass transition. The exploration of even deeper quenches (higher final volume fractions) up to the random close packing reveals that the suppression of long-time self diffusion occurs near maximum packing. Detailed study of structural and rheological evolution after the jump are utilized to elucidate the mechanistic process of glassy arrest.

Wednesday 12:30 Nettuno 2-3

SG7

Dry granular flows rheology: experimental investigation and particles simulationsGiulia Rossi¹ and Aronne Armanini²*DICAM, University of Trento, Trento, 38123, Italy*

Dry granular materials are ensembles of discrete particles, whose behavior may be assimilated to a gas or liquid or to a solid, according as they are agitated or at rest. Their complex characteristics lead to classify granular media as a new form of material, which stands in between the solid, liquid and gas states [1, 2]. Flows of granular material involve many natural phenomena (e.g. snow avalanches, rock avalanches, debris flows or pyroclastic flows) but also industrial applications (e.g. food or pharmaceutical industries). This wide presence of such type of flows in nature and industry, makes this topic of great interest for researchers. It is still lacking a proper rheological frame for this phenomena, capable to describe appropriately all its characteristics. The most diffused approach is that of applying the kinetic theory of gases [3]: the macroscopic particles are assimilated to the molecules of gases and the thermodynamic temperature is substituted with the granular temperature, i.e. the square of the velocity fluctuations of the particles. However, for high concentration of the granular media, this approach is not suitable: the basis of the kinetic theory consists in considering the contacts among particles instantaneous and binary. This is not true in dense granular flows, where long lasting

and multiples contact take place. We present a rheology which accounts both for the collisional regime (instantaneous and binary contacts) and for the frictional regime (prolonged and multiples contacts) through a modulating function f_0 . This function allows the coexistence and intermittency of the two regimes and depends on the concentration of the granular media. The rheology has been calibrated on experimental data and on Molecular Dynamics Simulations (MDS).

[1] Goldhirsch, I. (2003). Annual review of fluid mechanics, 35(1), 267-293. [2] Jaeger, H. M. et al. (1996). Reviews of modern physics, 68(4), 1259. [3] Jenkins, J. T., & Savage, S. B. (1983). Journal of fluid mechanics, 130, 187-202.

Symposium PG

Porous Media, Geo Fluids, Crude Oil & Derivatives

Organizers: Aronne Armanini and Valery Kulichikhin

Wednesday 10:00 Nettuno 4

PG1

Crude oils: wax crystallization and rheological behavior

Flavio H. Marchesini¹, Alexandra A. Aliche¹, Felipe L. Paiva², Paulo R. de Souza Mendes¹, and Veronica Calado²
¹Department of Mechanical Engineering, Pontificia Universidade Católica do Rio de Janeiro, Rio de Janeiro, RJ 22453-900, Brazil; ²School of Chemistry, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ 21941-909, Brazil

In this work, we investigate the most relevant methods used to obtain the Wax Precipitation Temperature (WPT) and the rheological properties of waxy crude oils. Three methods, namely polarized light microscopy, microdifferential scanning calorimetry (μ DSC), and rheometry, are employed to measure the WPT of a Brazilian waxy crude oil. In addition, a protocol is used to ensure well-defined thermal and shear histories of a waxy crude oil sample to be submitted to rheological measurements. Constant shear stress, constant shear rate, and steady state flow rheometric experiments are then performed to evaluate the rheological properties of the gelled crude oil at a temperature well below the WPT. Interesting phenomena are observed, including a non-monotonic flow curve, viscosity bifurcation, dependence of the yield stress on thermal and shear histories, and independence of the steady state results of the post-cooling initial condition of the experiment. Moreover, it is shown that the degree of sample confinement has a key role on the accuracy of the measurements, so that care must be taken when using laboratory data to design field operations.

Wednesday 10:20 Nettuno 4

PG2

Lubricated transport of very viscous oil in pipes

Baltasar Mena

Institute of Engineering, National Autonomous University of Mexico, Coyoacan, Ciudad de Mexico 04510, Mexico

Optimal conditions for the lubricated transport of very heavy crude oils in pipes are established. A dilute aqueous solution is used as the lubricating fluid and the heavy oil is transported in the core of the pipe. The pressure drop and therefore the pumping power required to transport the oil is fifty times smaller when lubrication is used. The outer flow is turbulent whilst the core flow is laminar. When conditions of viscosity, temperature and pressure in the injection nozzle are maintained within a certain range, 70% heavy oil can be transported with 30% lubricating solution. The flow remains stable regardless of the wall temperature of the pipe.

Wednesday 10:40 Nettuno 4

PG3

Effect of solvents on the asphaltene aggregation in a heavy crude oil

Claudia Carotenuto¹, Maria C. Merola², and Mario Minale¹

¹Industrial and Information Engineering Department, University of Campania Luigi Vanvitelli, Aversa, Italy; ²Life Science Division, Alcedim, Merle, Lyone 69003, France

Nowadays unconventional oils represent the vast majority of the world oil reserves and thus both the scientific and technical interests on their exploitation are significantly increasing. These crude oils are very viscous, thus their production, transportation and refining result very expensive. Typically, they are diluted in various solvents to be efficiently transported. Asphaltenes are the main responsible for their high viscosity and their eventual non-Newtonian behaviour. In this paper we study the asphaltene aggregation in a heavy crude oil in response to the addition of solvents with different quality by measuring the intrinsic viscosity and the Huggins coefficient. We show that the oil microstructure changes with the solvent quality thus indicating that the asphaltenes in the oil are already aggregated to form clusters. The response to poor solvents may vary significantly, indeed, a mixture C11-C14 of alkanes induces the cluster aggregation, while a diesel cluster shrinkage. Moreover, we show that if the diesel oil is added in small quantities instead of a cluster shrinkage it may induce a cluster aggregation. The obtained "macro-clusters" are stable upon dilution in both poor and good solvents and are more soluble than the original cluster, as the Huggins coefficient is minimized when they are formed. Finally, an unusual negative Huggins coefficient is measured when the macro-clusters are formed and the solution is diluted in a good solvent. This might be explained by distinguishing the inter-macro-cluster interactions from the intra-macro-cluster ones.

Wednesday 11:30 Nettuno 4

Keynote PG4

Water-in-crude oil emulsions: stability, separation, bulk rheology, and interfacial rheologyPaulo R. de Souza Mendes¹, Alexandra Alicke², Bruna C. Leopércio¹, Ivan Jr. Leitão³, and Børre T. Børresen⁴¹*Department of Mechanical Engineering, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, RJ 22451900, Brazil;* ²*Department of Materials, ETH Zürich, Zürich, Switzerland;* ³*Statoil, Rio de Janeiro, Brazil;*⁴*Statoil, Rotvoll, Norway*

During the production of crude oils, flows through electrical submersible pumps (ESPs), valves, and chokes may produce rather stable water-in-oil (W/O) emulsions. This phenomenon leads to pressure peaks in pumps due to a major viscosity increase. Depending upon the amount of dispersed water, the emulsion separation or inversion (to an oil-in-water emulsion) is possible and highly desirable. Therefore, oil companies have a particular interest in the flow behavior and stability of W/O emulsions. Moreover, model oils are frequently used to mimic the behavior of the crude oil, since model oils are easier and safer to use in laboratory benchtop flow experiments, such as in narrow gap homogenizers and stirred tanks, which offer insight into emulsion formation and serve for upscaling to real field conditions. To this end, we studied the rheological behavior of both model and crude W/O emulsions at different water cuts to determine their stability, separation properties, and the relation between the flow behavior, stability, and microstructure. In addition, we studied the effect of an emulsion breaker on the bulk rheology and also on the rheology of the water-crude oil interface. Among other findings we observed that two effects are brought by the presence of the emulsion breaker, namely the reduction of the water cut and the reduction of the interfacial viscosity. These two effects contribute to the reduction of the bulk viscosity.

Wednesday 12:10 Nettuno 4

PG5

Spontaneous emulsification in the presence of asphaltenesSimone Bochner de Araujo¹, Cecile Monteux², Mathilde Reyssat³, and Gerald G. Fuller¹¹*Department of Chemical Engineering, Stanford University, Stanford, CA, United States;* ²*Soft Matter Science and Engineering, ESPCI - Paris, Paris 75005, France;* ³*Gulliver, ESPCI - Paris, Paris 75005, France*

Asphaltenes are complex polar components of heavy oils and are only marginally stable in organic solvents. Because of this marginal solubility, they have a propensity to adsorb onto oil/water interfaces to form viscoelastic layers. In addition, the contact of water against a solution of asphaltenes dissolved in a model hydrocarbon (such as toluene) induces a spontaneous emulsification phenomenon where micron-size water droplets, stabilized by asphaltenes, spontaneously appear. These can result in a strong stabilization of water-in-oil emulsions that cause difficulties in refining operations. In this work, we examine the spontaneous emulsification phenomenon in the presence of asphaltenes. First, the evolution of an oil/water interface and the spontaneous appearance of micron-size droplets are observed using a confocal microscope. Then, a microfluidic device is used to monitor the development of the spontaneous emulsification phenomenon at the surface of a single water drop in oil. The asphaltene concentration in solution, the solvents ratio (toluene and heptane are used) and the drop size are varied. Finally, we examine the influence of the proximity of other water drops on the spatial distribution of the spontaneously emulsified droplets at a water drop interface. We find that the drop size has a strong effect on spontaneous emulsification dynamics. Moreover, higher concentrations of asphaltene yields faster spontaneous emulsification phenomenon.

Wednesday 12:30 Nettuno 4

PG6

Experimental investigation of the effect of hydrophilic nanoparticles on the rheological behavior of hydrolyzed polyacrylamide polymers: application in enhanced oil recoverySeyyed Shahram Khalilnezhad¹, Ghasemi Mojtaba², Sina Mobaraki³, and Khosro Jarrahian⁴¹*Petroleum Engineering, Eqbal Lahoori Institute of Higher Education, Mashhad, Iran;* ²*DeGolyer and MacNaughton, Dallas, TX, United States;* ³*Science and research branch, Islamic Azad University, Young Researchers and Elite Club, Tehran, Iran;* ⁴*Institute of Petroleum Engineering, Heriot Watt University, EH14 4AS, Edinburgh, United Kingdom*

Improvements in the performance of chemical enhanced oil recovery techniques using nanofluids is of great interest. Despite the extensive research in this area, the role of hydrophilic nanoparticles on the microscopic and macroscopic sweep efficiencies during polymer flooding is still an immature subject. As the subject of rheology is important to interpret the flow behavior of the polymeric solutions through porous media, the visco-elastic properties of the polymer solutions with or without Dispersed Silica Nanoparticles (DSN) were analyzed through utilizing rheological measurements. Accordingly, the effect of the presence of DSN on the thermal stability and salt tolerance of two types of Hydrolyzed Polyacrylamide (HPAM) polymers with different molecular weights were investigated. The flow behavior of the candidate solutions through low-permeability carbonate cores was also examined by the use of core flood experiments. To understand the microscopic sweep efficiency of the Dispersed Silica Nanoparticles in Polymer (DSNP) solutions, the micromodel experiments were carried out and the captured microscopic pictures were carefully examined. Finally, both rheological responses and the results of oil recovery experiments were modeled using UTCHEM simulator. In addition to the results of optical absorption measurements indicating the relatively long-term stability of the DSNP solution, the rheological measurements showed the significant ability of silica nanoparticles to prevent polymer degradation in the presence of salt. Furthermore, the DSN could improve the thermal stability of polymers by a factor of 10%. The core flood experiments demonstrated significant recovery improvement by DSNP, an ultimate recovery factor of approximately 75 percent. Pore-scale observations disclosed that the pulling effect and stripping mechanisms were the main responsible mechanisms for high microscopic sweep efficiency during DSNP flood which would be attributed to the improved viscoelastic behavior of the polymer solutions.

Symposium BE

Blends, Emulsions, Foams & Interfacial Rheology

Organizers: Ernesto Di Maio, Peter Van Puyvelde and Jan Vermant

Wednesday 10:00 Nettuno 5-6

BE1

Interrelationship between bulk and interfacial rheology of emulsions stabilized with clay particlesJOUNG SOOK HONG¹, Peter Fischer², and Kyung Hyun Ahn¹¹*Institute of Chemical Processes, Seoul National University, Seoul 08826, Republic of Korea;* ²*Institute of Food, Nutrition and Health, ETH Zurich, Zurich 8092, Switzerland*

The stabilizing effect of clay particles on oil-in-water emulsions was investigated using bulk and interfacial rheological measurements. With organically modified montmorillonite (OMt) which is hydrophobic, the emulsion was stabilized by increasing the bulk modulus of the oil phase (G^*_{oil}) as the matrix phase which causes a significant delay of phase separation. If OMt was present together with natural clays (NMT), clays built up a complex interface at the oil-water interface which significantly influenced the bulky/interfacial rheological response and emulsion stability. Storage modulus of the emulsion ($G^*_{emulsion}$) as well as interfacial modulus increased significantly. The high interfacial modulus ($G^*_{interface}$) of the composite interface stabilized the flocculated droplets more than the repulsive interaction between droplets as interfacial area (oil-to-water ratio) increased. Then, with increasing interfacial area, microscopic and macroscopic stabilization of emulsions was improved.

Wednesday 10:20 Nettuno 5-6

BE2

Dilatation mechanics and bubble coalescence of monoclonal antibody interfacesAadithya Kannan¹, Ian C. Shieh², Danielle L. Leiske³, and Gerald G. Fuller¹¹*Department of Chemical Engineering, Stanford University, Stanford, CA, United States;* ²*Late Stage Pharmaceutical Development, Genentech, San Francisco, CA, United States;* ³*Early Stage Pharmaceutical Development, Genentech, San Francisco, CA, United States*

Monoclonal antibodies (mAbs) are therapeutic proteins that uniquely recognize and neutralize pathogens. These molecules readily adsorb to air-solution interfaces to form a viscoelastic network that can lead to aggregation. This affects the quality and the immunogenicity of the drug. In mAb product vials and IV bags, air entrainment is inevitable. These bubbles approach the headspace and eventually coalesce. The thin film drainage behavior leading up to coalescence and the dynamics of the entrapped thicker region near the bubble's apex (a dimple) is governed by the nature of the bounding interfaces. We studied two mAbs provided by Genentech with different tendencies to aggregate. Using a custom-built bubble dilatational rheometer, air bubbles were created in mAb solution and the stress relaxation after a step compression was measured. The relaxation data followed a single exponential decay according to the Kelvin model and the initial and the equilibrated values of the moduli showed a dependence on the interface age and the mAbs' aggregation tendency. We used a dynamic fluid-film interferometer to study the thin film drainage as a bubble approaches a flat interface in the presence of mAbs. The time to coalesce depended on the age of the interface. To study the effect of surfactants in mAb formulations, we used two polymeric surfactants: polyethylene glycol and poloxamer-188. Confocal imaging of fluorescently tagged mAbs with surfactants revealed domain structures with varying mAb surface coverage at different concentrations. This was reflected in the relaxation and coalescence behavior. During film drainage, higher surfactant concentration cases exhibited a mobile dimple with Marangoni flows induced by surfactant concentration gradients. Conversely, the lower surfactant concentration cases had an immobile dimple due to the interfacial viscoelasticity. This work shows how the interfacial nature of these viscoelastic proteins and protein/surfactant mixtures can be characterized by film drainage studies.

Wednesday 10:40 Nettuno 5-6

BE3

Impact of adsorbed colloidal complexes on fluid-fluid interfacesMichael L. Davidson and Lynn M. Walker*Chemical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, United States*

Complexation of colloidal species (particles, proteins, macromolecules) and surfactant in bulk solution has long been used to generate complexes of different geometry, size, and surface chemistry. These complexes will have different interfacial properties than the individual components allowing for the formation of irreversibly adsorbed and elastic interfaces. The detailed control of these interfaces for optimization of interfacial properties is necessary. We are developing the knowledge and tools to have this control and also generating a characterized library of interfaces for study of phenomena like coalescence, deformation and break up of fluid-fluid interfaces. The properties (interfacial tension and interfacial rheology) of fluid-fluid interfaces with polymer-surfactant complexes and particle-surfactant complexes adsorbed will be discussed. Of specific interest is the ramifications of complex properties on these interfacial properties. Most characterization of interfaces is performed to extract isotherms, or equilibrium and steady-state behavior. For processing, the more relevant information is the transient state; knowledge of transport time scales will have a significant impact on the design of processes. One example with demonstrate the ability to alter interfacial mechanics thought nonlinear deformation of interfaces. This ability to control and generate different interfacial properties through deformation of the interface is important for processing of multicomponent layers.

Wednesday 11:30 Nettuno 5-6

BE4

Transient string formation in colloid monolayers at fluid interfaces under ultrafast deformationAxel Huerre, Marco De Corato, and Valeria Garbin*Chemical Engineering, Imperial College London, London SW7 2AZ, United Kingdom*

Droplets and bubbles stabilized by a monolayer of microparticles are exploited in encapsulation and catalysis. Particle-stabilized bubbles are the building blocks of lightweight materials based on foams, and are central in enhanced oil recovery. Despite their importance in applications, our fundamental understanding of the behaviour of particle-laden interfaces under dynamic deformation remains limited. While shear rheology has been the focus of recent research, the effect of compression remains largely unexplored. Our experiment aims at understanding the link between the microstructure and the rheological properties of the interface. To impart controlled, dynamic compression of a particle-laden interface, we subject particle-coated bubbles to ultrasonic driving. This method enables us to achieve compression-expansion of the monolayer in the frequency range 10-100 kHz. The bubbles (60-400 μm), stabilized by a monolayer of microparticles (1-10 μm), are monitored with high-speed video microscopy to resolve the evolution of the monolayer. The periodic oscillation of the interface drives qualitatively different evolution of the monolayer compared to what is commonly observed under shear deformation. Specifically, the particles self-assemble into a network of strings. At this ultrafast timescale, the particle's inertia causes a deformation of the interface leading to transient capillary interactions. Particle-based simulations show that the emergence of strings can be explained by the coupling of this transient deformation with the equilibrium deformation initially present due to nanoscale undulations of the contact line. This work provides the first demonstration of unique dynamical phenomena upon extreme deformation of complex fluid interfaces, and lays the foundations for studies of high-frequency rheology of particle-laden interfaces.

Wednesday 11:50 Nettuno 5-6

BE5

Surface behaviour of vegetable protein by pendant drop methodNoemi Baldino, Olga Mileti, Francesca R. Lupi, Domenico Gabriele, and Bruno de Cindio*DIMES Department, University of Calabria, Rende, Cs 87036, Italy*

Many food products are multiphase systems and their structural and textural properties are determined by the interactions between the various macromolecules making up the system. They are created by homogenization of two or more immiscible phases, to form emulsions or foams. Typically, examples of these are salad dressing, mousse, whipped topping, ice-cream, bread. The homogenization process takes away with an increase in energy necessary to form many interfaces and the interfacial layers' formation may give rise to natural phase separation phenomena. Then, it is necessary to stabilize these systems by use of surface-active agents, which can be low molecular-weight emulsifiers or macromolecules like proteins. Proteins are widely used to create foams or emulsions. They are polymers of amino acids and due to their amphiphilic structure, they can adsorb quickly to interfacial layers. Their presence leads to interfacial tension decrease and improves the mechanical resistance of the interfacial layers. Recently, protein extract from vegetable seeds have been receiving much attention from food industry, thanks to their good environmental sustainability and healthy composition, but the study of their surface properties is very important to stabilization and formulation of emulsions and foams. Then, on the light of the above in this work, it has been investigated the surface properties of two protein extract from vegetable source, soy and hemp, using the pendant drop method and analyzing systems at different protein level. Static measurements of surface tension versus time have been performed in the concentration range that take to have the equilibrium isotherm. Dilatational rheological properties have been studied too by oscillating pendant drop method. Finally, to test the relaxation mechanisms of interfacial layer, compression/expansion of the drop with a defined volume variation have been investigated.

Wednesday 12:10 Nettuno 5-6

BE6

Interfacial rheology of bacterial biofilmsClémence Abriat¹, France Daigle², Nick Virgilio¹, and Marie C Heuzey¹¹*Polytechnique Montréal, Montreal, Canada;* ²*Université de Montréal, Montreal, Canada*

Bacteria tend to live predominantly in communities called biofilms. These biofilms are associated with biofouling, food and water contamination, and bacterial infections resulting in both economic and human costs. The bacterial cells are embedded in an extracellular matrix (ECM) composed of polymeric substances secreted by the bacteria and can be located at the air-liquid interface in which case they are called pellicles. Biofilms are very complex structures comprising various microorganisms and a better characterization of the ECM properties is required to disturb them. Interfacial rheology is a unique method to quantify the biofilm strength during its formation over time at the air-liquid interface. Whereas most studies focus on mono-species biofilm, we used a model dual-species biofilm composed of two bacteria commonly found in multiple food contamination and food poisoning cases: *Bacillus licheniformis* and *Pseudomonas fluorescens*. We measured the viscoelastic growth profile of the model dual-species biofilm during its formation and confirmed that interfacial rheology is suitable for our system. We also studied the influence of interactions among species - antagonist in our case with competition for nutrients and growth inhibition - on the biofilm strength through interfacial rheology measurements. The rheology quantitative information is validated and complemented by microbiology experiments of the ECM, growth kinetics and microscopic analysis. Altogether, we were able to relate the unique changes in viscosity and elasticity of the dual-species biofilm to interspecies interactions, providing fundamental knowledge required to biofilm removal.

Wednesday 12:30 Nettuno 5-6

BE7

Dilatational viscoelasticity of a polymer multilayer system at the air-water interfaceMartina Pepicelli¹, Jan Vermant¹, Theo Tervoort², and Cecile Monteux³¹*Material engineering, ETH Zurich, Zurich, Switzerland;* ²*ETH Zurich, Zurich, Switzerland;* ³*Soft Matter Science and Engineering, ESPCI - Paris, Paris 75005, France*

In this work, a polymeric system based on multiple layers of soluble yet surface-active polymers, is chosen as viscoelastic model system with the aim of investigating the effects of viscoelasticity and non linear behaviour in shear and, for the first time, in dilation, using a radial trough apparatus [1]. The different polymeric layers were assembled at the air-water interface with a layer-by-layer

method, taking advantage of a thermodynamically driven adsorption process. Once adsorbed at the interface, these layers form a practically insoluble network with enhanced viscoelastic properties [2]. The possibility of studying the individual layers, under shear and dilatational deformations, enabled the independent quantification of the thermodynamic properties. Therefore, the time and frequency dependent material functions could be separated and correctly determined. Furthermore a neo Hookean model [1] for elastic interfaces was adapted to describe a viscoelastic system by having the material properties to be function of time. The use of this model made it possible to correctly calculate the dilatational properties of the system, in within the limit of the linear viscoelastic regime. Moreover, the onset of non-linear behaviour was characterised in shear and for the first time in dilation.

[1] Pepicelli, M. et al. (2017). *Soft matter*, 13(35), 5977-5990. [2] Le Tirilly, S. et al. (2014). *ACS Macro Letters*, 4(1), 25-29.

Wednesday Afternoon

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Wednesday 14:20 Sirene

CS8

Effects of shape on the dynamics of concentrated solutions of polymer-grafted nanoparticles

Daniele Parisi¹, Yingbo Ruan², Benoit Loppinet³, Chen-Yang Liu², and Dimitris Vlassopoulos¹

¹Department of Materials Science and Technology, FORTH-University of Crete, Heraklion, Greece; ²Institute of Chemistry-Chinese Academy of Sciences, Beijing, China; ³FORTH-Institute of Electronic Structure and Laser, Heraklion, Greece

We present a systematic investigation of the structure and dynamics of polymer-grafted nanoparticles (NPs) in solution with particular attention on the role of shape. To this end, we compare three NP systems with the same chemistry, similar grafting density, same grafted arm molar mass but different core shape (spheres, cylinders and lamellas). Light, X-ray and neutron scattering are used to characterize their static and dynamic properties, whereas different rheological protocols provide information on linear and nonlinear viscoelastic response. Our results show unambiguously that particle shape and organization govern the elasticity and relaxation dynamics in the dense (glassy) state in equilibrium conditions when the three systems are compared at the same mass fraction. At similar packing fraction, the short-time dynamics seems to be particle-shape independent when the data are properly rescaled by the elasticity and the fast characteristic time (associated to beta relaxation), hence the shape of the particle only affects long-time dynamics. The glassy regime appears to involve frozen domain with local orientational order akin to glasses of other, charge-stabilized anisotropic colloids. The dependence of yield stress on Weissenberg number sets non-spherical NPs apart from the spherical ones, and the concept of cage elasticity is invoked in order to rationalize the observed differences. On the other hand, the yield strain is of the order of 10%, in agreement with most glassy colloidal systems.

Wednesday 14:40 Sirene

CS9

Biaxial extensional rheology of shear thickening fluids

José A. Ruiz-López¹, John Royer², and Mark Haw¹

¹Department of Chemical Engineering, University of Strathclyde, Glasgow G1 1XJ, United Kingdom; ²School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD, United Kingdom

Shear-thickening fluids are a kind of non-Newtonian fluids where the viscosity increases with the shear rate. Some dense suspensions, particularly those with strong repulsive interactions among particles have been reported to behave as shear thickening fluids [1]. Above certain particle concentration, the viscosity of the suspension sharply increases beyond a critical shear stress leading to the so-called discontinuous shear thickening [2]. This fact has been recently explained by the frictional contacts between particles induced by the shear flow in experiments and simulations. Despite the numerous studies dealing with the shear rheology of dense suspensions and their shear-thickening behavior, little attention has been paid to the extensional rheology of these suspensions even though the extensional rheological behavior is interesting for industrial processes and their rheological properties might differ from shearing. In this work, we studied the rheological properties of different fluids under compression carrying out constant-area biaxial-extensional tests in a rough plate-plate geometry at constant elongational rate. Results from Newtonian fluids show that the normal force increases during compression reaching a nearly constant value at high strains (i.e. low gaps). These results were fitted to theories for perfect-stick rough walls obtaining that the fitting viscosity was reasonably in agreement to the actual viscosity of the fluid. However, the viscosities obtained for corn-starch dense suspensions were quite different from their viscosities in shear flow. Whereas, at intermediate concentrations, the fluid is shear-thickening; the viscosity decreases with the elongational rate in compression tests. This thinning behavior reversed for higher concentrations to a thickening behavior both in shear and elongational flows.

[1] Wagner, N. J., & Brady, J. F. (2009). Physics Today, 62(10), 27-32. [2] Guy, B. M. et al. (2015). Physical review letters, 115(8), 088304.

Wednesday 15:00 Sirene

CS10

Influence of latex SBR binder on the rheological and adhesive properties of capillary suspension battery slurries

Jieun Park¹, Norbert Willenbacher², and Kyung Hyun Ahn¹

¹Seoul National University, Seoul, Republic of Korea; ²Institute for Mechanical Process Engineering and Mechanics, Karlsruhe Institute of Technology, Karlsruhe 76131, Germany

Li-ion batteries are attracting wide attention as a promising material in the fields of energy storage. Capillary suspensions, which exploit capillary force induced by a small amount of the secondary fluid to develop network structure, provide an innovative alternative for battery slurries. Structure modification induced by capillary suspensions improves rheological and coating properties of the battery slurries. However, the addition of the secondary fluid on battery slurries could have a negative effect on mechanical properties. Mechanical properties are controlled by additives such as binders. Since capillary suspensions mainly focused on the

ternary system which consists of particles, bulk fluid and the secondary fluid, the effect of the secondary fluid on additives in battery slurries has not yet been thoroughly investigated. This concept could be properly applied with an adequate understanding of the influence of the secondary fluid on battery slurries. Therefore, the interaction between the binder and the secondary fluid needs to be examined prior to apply this concept to industrial slurries. In this study, the interaction between styrene-butadiene rubber (SBR) binder of Li-ion anode battery slurry and the secondary fluid, octanol, was determined by sample mixing condition and binder volume fraction. Consequential variations in mechanical properties such as rheological properties and adhesion characteristics were measured. Microscopic images and interfacial tension data corroborate the explanation of the role and the distribution of the binder in the capillary suspensions. An enhanced understanding of this interaction in this study allows to optimize targeting mechanical properties in the battery slurries based on capillary suspensions.

Wednesday 15:20 Sirene

CS11

Jet instability of a shear-thickening suspension of solid particles

Maxime Liard¹, Didier Lootens¹, and Pascal Hébraud²

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The jet properties of concentrated silica particles suspensions have been investigated through image analysis of its shape using a high speed camera. The suspension is loaded into a funnel and is let free to fall under its own weight. It has been observed that several instabilities develop along the falling jet. At intermediate concentrations, surface instabilities lead to droplet formations, but at higher concentration of particles, when the suspension starts to shear thicken at low shear, the jet becomes unstable and is no longer vertical. The falling filament is longer, the surface instabilities disappear and the filament starts to oscillate at a high frequency (10 Hz). The origin of those oscillations have been studied and a rope-like model can partially explained this phenomena; moreover the measurement of the weight of the falling filament displays discontinuities which may be attributed to fast solid/liquid transition during the experiment and justify our approach.

Wednesday 15:40 Sirene

CS12

High frequency rheology of colloidal dispersions: from hard to soft, from smooth to frictional

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Colloidal dispersions are an interesting class of materials that can display a wide range of rheological behavior such as a yield stress, shear thinning, and shear thickening. Their rheological response is inherently viscoelastic as a result of Brownian relaxation, and is further governed by hydrodynamic and thermodynamic forces. High frequency rheology has proven very useful to study the local structure and interactions of colloidal dispersions up to high particle concentrations. In this work, a home-built piezo shear rheometer is used in parallel with a commercial device to perform frequency sweeps over an extended range from 0.01-2000 Hz. This allowed to investigate timescales much faster than the diffusional motion of the particles in the dispersion. The aim of the work is twofold. Dispersions of PMMA-g-PHSA particles with varying lengths of PHSA stabilizer were used to systematically vary the size of a thermodynamic hard sphere radius to the hydrodynamic radius. As such, it is shown that the asymptotic behavior towards the high frequency limit is very sensitive to the dominant interparticle interactions which act on a more local scale. Attractive interactions can further alter the linear viscoelastic response. Secondly, investigating the asymptotic behavior of smooth and model rough silica particles with well-defined asperities determined the role of frictional interactions versus lubrication forces in the local dynamics of model rough colloids. Description of these interactions under dynamic conditions play an important role in understanding the onset of continuous and discontinuous shear thickening of colloidal dispersions.

Wednesday 16:30 Sirene

CS13

Understanding shear thinning of dense suspensions through simulations

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Understanding the shear rheology of dense suspensions is important for a variety of industrial processes and applications. Recent experimental evidence shows that with increase in shear rates/stress, there are two shear thinning regimes separated by a shear thickening regime [1]. Using numerical simulations of lubricated particles, we corroborate the experimental findings and hypotheses. We show that i) short ranged repulsive interactions give rise to the initial shear thinning region, ii) frictional interactions between the particles cause shear thickening, and iii) a decrease in particle friction at higher loads leads to the second shear thinning region.

[1] Chatte, G., Comtet, J., Nigues, A., Bocquet, L., Siria, A., Guylaine, D., Lequeux, F., Lenoir, N., Ovarlez, G., and Colin, A., Oct 2017, manuscript under review

Wednesday 16:50 Sirene

CS14

Dynamics of shear-thickening dispersions

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Maizena is a shear thickening dispersion. Above a critical shear rate, its viscosity diverges. In this regime, the maizena displays a peculiar dynamics when solicited at a constant stress. We use a rheometer synchronized with echography measurements to monitor the local deformation within the sheared maizena to study the dispersion dynamics. We find that the dispersion always flows homogeneously and is scattered with spatio-temporal events which set the time scales. We believe that those events correspond to the rupture of elastic chain within the suspension.

Wednesday 17:10 Sirene

CS15

Liquid migration during extrusion of concentrated shear thickening suspensionsRory O'Neill, John Royer, and Wilson Poon*School of Physics and Astronomy, The University of Edinburgh, Edinburgh, United Kingdom*

Extrusion of concentrated suspensions through a constriction in a die is ubiquitous in applications, but the underlying physics is far from understood. To date, no model is capable of adequately predicting the range of possible behaviour [1], and much of industrial practice consists of trial and error. We investigate the extrusion of a model shear thickening suspension (corn starch particles suspended in glycerol/water) and connect the extrusion dynamics to recent advances understanding shear thickening. In these suspensions, the formation of frictional contacts under shear [2] results in an increased viscosity that diverges at a volume fraction ϕ_m substantially below random close packing [3], so that steady flow in simple shear becomes impossible at high stresses [4]. In extrusion, we find a critical volume fraction ϕ_c where suspensions below ϕ_c can be extruded homogeneously but above ϕ_c liquid migration occurs, decreasing the solid concentration of the extruded material. In contrast to previous work [5], here we find that ϕ_c decreases with increasing flow rate, possibly related to the absence of a yield stress in our model suspension. While ϕ_c is greater than ϕ_m at low flow rates and in wide die exits, as the flow rate increases and die diameter decreases ϕ_c appears to approach ϕ_m , suggesting that frictional contacts and the criteria for steady flow under simple shear play a critical role governing liquid migration.

[1] Patel, M. J. et al. (2017). Chemical Engineering Science, 172, 487-502. [2] Lin, N. Y. et al. (2015). Physical review letters, 115(22), 228304. [3] Guy, B. M. et al. (2015). Physical review letters, 115(8), 088304. [4] Hermes, M. et al. (2016). Journal of Rheology, 60(5), 905-916. [5] O'Neill, R. et al. (2016). Journal of Materials Science: Materials in Medicine, 27(2), 29.

Wednesday 17:30 Sirene

CS16

Contact forces and particle interactions in shear thickening suspensionsJohn Royer, Joseph French, and Wilson Poon*School of Physics and Astronomy, The University of Edinburgh, Edinburgh, United Kingdom*

Dense suspensions are ubiquitous in industrial applications - cements, chocolate and ceramic pastes etc., but their flow is notoriously difficult to manage. Much of this difficulty arises because as particles come into close contact, the macroscopic suspension rheology becomes increasingly controlled by micro- and nano-scale details of the particle interactions. This is exemplified in shear thickening, where the dramatic viscosity increase arises from a stress-dependent contact friction between particles [1-3]. While friction-based models and theories capture many aspects of shear thickening observed in experiments [4, 5], the criteria controlling the formation of frictional contacts has not been firmly established. Here we investigate shear thickening in suspensions of charge-stabilised silica spheres, allowing us to continuously tune the particle interactions by varying the fluid ionic strength. As the ionic strength is increased from low to moderate values, decreasing both the magnitude and range of the repulsive electrostatic interactions, the onset stress decreases while the flow curves maintain the characteristic shape predicted by friction-based theories. This persists even as the screening length becomes smaller than the particle surface roughness, setting a tight upper bound on any possible gaps between particles at the thickening onset. At higher ionic strengths, the onset stress rapidly vanishes and a yield stress develops as repulsive electrostatic interactions give way to attractive van der Waals forces. Using Atomic Force Microscopy to characterise the particle surface properties and interactions, we directly connect these changes in the shear thickening behaviour to the inter-particle forces.

[1] Guy, B. M. et al. (2015). Physical review letters, 115(8), 088304. [2] Royer, J. R. et al. (2016). Physical review letters, 116(18), 188301. [3] Comtet, J. et al. (2017). Nature communications, 8, 15633. [4] Seto, R., et al. (2013). Physical review letters, 111(21), 218301. [5] Wyart, M., & Cates, M. E. (2014). Physical review letters, 112(9), 098302.

Wednesday 17:50 Sirene

CS17

Wall slip and concentration measurements by means of modified PIV methodsSteffen Jesinghausen and Hans-Joachim Schmid*Particle Technology, Paderborn University, Paderborn, Germany*

Wall slip in general and specifically in suspensions has long been known. However, because of its complexity, there is no general slip theory. Recent advancements in the field of measuring technology allow for new investigations and more profound understanding. The main reason for wall slip in suspensions are the migration and structuring of particles that result in a particle depleted layer near the wall with substantially lower viscosity than the bulk. Therefore, the suspensions seems to slip at the wall when shear flow is instead just localized in this thin layer. These slip layers have dimensions in the low micron range and are hardly accessible. At first sight, optical methods seem inappropriate to investigate the flow of suspensions as they lack transparency. However, if carefully index matched, model suspensions can appear sufficiently transparent. The advantage of optical systems is the high adaptability to different geometries at reasonably low costs. Furthermore, transient measurements are possible as data acquisition is comparatively fast. Unfortunately, their spatial resolution is typically not good enough to measure the wall slip velocity. We developed a new optical method to visualize the flow field of transparent suspensions on a micron scale. To this end, the known methods of Particle Image Velocimetry and Speckle Velocimetry were combined and by use of a local illumination, the signal to noise ratio was considerably improved. Thus, compared to the standard methods, wall slip can be observed directly. Additionally, an indirect method to derive the concentration profiles from the velocity profiles as a first indication for the particle structuring will be presented. Thus, two valuable variables for the understanding of the phenomenon of wall slip can be measured at the same time. The presented method is by far more reliable to detect wall slip in suspensions than classical integral methods reported in the relevant literature.

Symposium NF

Non Newtonian Fluid Mechanics & Flow Instabilities

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Wednesday 14:20 Ulisse

NF8

Acoustically enhanced bubble removal from yield stress fluidsMarco De Corato, Axel Huerre, Diego Baresch, and Valeria Garbin*Chemical Engineering, Imperial College London, London SW7 2AZ, United Kingdom*

Yield stress fluids are widely encountered in many industrial areas such as formulated products, oil recovery, and wastewater treatment. In these applications, small gas bubbles are often generated in the fluids, or they are trapped while processing the fluid. Once suspended in a yield stress fluid, micron-sized bubbles are difficult to remove due to their small buoyancy force. The presence of trapped bubbles may affect the product quality or process performance, hence methods for removal of bubbles from yield stress fluids are desirable. We explore the use of ultrasound waves to release micron-sized bubbles from yield stress fluids. Preliminary experiments performed in our lab suggest that micron-sized bubble can become free to escape after less than a minute of exposure to ultrasound. We hypothesize that, due to the high-frequency oscillations of the bubbles in the ultrasound field, extensional rates in the range 10^4 - 10^6 s⁻¹ are applied to the surrounding fluid, causing local yielding. We develop a theoretical framework to describe the ultrafast deformation of yield stress fluids by acoustically driven microbubbles. We modify the Rayleigh-Plesset equation governing the radial dynamics of the bubble to take into account the complex behaviour of the fluid. We characterize the amplitude of the radial oscillations of the bubble as a function of the ultrasound frequency, and for different rheological parameters, by solving the Rayleigh-Plesset equation, numerically. By quantifying the volume of fluid that is yielded as a function of the amplitude and frequency of the acoustic pressure, it is possible to predict optimal conditions for bubble removal.

Wednesday 14:40 Ulisse

NF9

Analysis of flow development in yield stress fluidsIda Karimfazli¹ and Ian A. Frigaard²¹*Mechanical, Industrial & Aerospace Engineering, Concordia University, Montreal, QC, Canada;* ²*Mechanical Engineering, University of British Columbia, Vancouver, Canada*

Most fluids in nature and industry respond to mechanical stress and strain in rather unusual ways compared with normal fluids like water: toothpaste, ketchup, cement slurry and basaltic lava flow only if the applied shear stress surpasses the fluids' yield stress. The distinctive feature of fluids with a yield stress, in comparison with purely viscous fluids, is that they may remain motionless when subject to shear stress. Predicting whether and how different body forces promote fluid flow is key for effective design of process that involve yield stress fluids. We explore the underlying hydrodynamic mechanisms of flow development and propose a reduced model that predicts key flow features in different settings. When the body force is constant, we establish the sufficient conditions that lead to a motionless steady state and examine the stability characteristics. Illustrative natural convection flows are used to depict flow dynamics subject to time-dependent body forces. Necessary conditions for immediate or delayed flow onset as well as temporary fluid flow are presented.

Wednesday 15:00 Ulisse

NF10

Dynamic slip of polydisperse linear polymers using partitioned plateEbrahimi Marzieh¹, Vinod Kumar Konaganti², and Savvas G. Hatzikiriakos³¹*Chemical and Biological Engineering, University of British Columbia, Vancouver, Canada;* ²*Chemical and Biological Engineering, The University of British Columbia, Vancouver, Canada;* ³*Chemical and Biological Engineering, The University of British Columbia, Vancouver, BC, Canada*

The slip velocity of a high molecular weight high-density polyethylene (HDPE) is studied in steady and dynamic shear experiments using the stress/strain controlled rotational rheometer equipped with parallel partitioned plate geometry. Moreover, fluoroalkyl silane-based coating is used to understand the effect of surface energy on slip in steady and dynamic conditions. The multimode integral Kaye-Bernstein-Kearsley-Zapas (K-BKZ) constitutive model is applied to predict the transient shear response of the HDPE melt obtained from rotational rheometer. It is found that a dynamic slip model with a slip relaxation time is needed to adequately predict the experimental data at large shear deformations. Comparison of the results before and after coating, shows that the slip velocity is largely affected by surface energy. Decreasing surface energy by coating increases slip velocity and decreases the slip relaxation time.

Wednesday 15:20 Ulisse

NF11

Exit effects in the wall slip of polymeric concentrated suspensionsValentina Mazzanti and Francesco Mollica*Department of Engineering, University of Ferrara, Ferrara, Italy*

In this work we have studied the rheological properties of a 50 wt.% wood flour filled polypropylene. Experiments have been performed with an instrumented slit die attached to a single screw extruder, the melt temperature has been kept at 195°C to reduce possibility of natural fiber degradation. The slit die had a variable gap height in order to use the Mooney procedure to measure wall slip. Non-Newtonian effects have also been taken into account using the Rabinowitsch correction procedure, while the Bagley correction is not needed in this case since pressure drop could be measured directly through three pressure transducers that are flush mounted in the die. As a result, a slip law and a flow rule could be determined experimentally. Now, if one uses these slip law and flow rule and solves them to check on the experimental pressure readings, it can be found that the theoretical pressures overestimate

the experimental measurements and moreover that the experimental pressure drop is non-linear close to the exit. This result can be explained by assuming that slip velocity increases in the last portion of the slit die, i.e. close to the exit, as a consequence of pressure dependent wall slip. A pressure dependent slip model has been then proposed, its specific equations numerically solved and the results fitted to the experimental pressure data, yielding a better fit. As pressure dependence of slip velocity induces a non-fully developed flow, it is clear that one of the hypotheses which are at the basis of the Mooney procedure is not satisfied by this fluid, thus strictly speaking the Mooney procedure is inapplicable. In fact, if one simulates the Mooney plot using the pressure dependent slip model it is possible to see that the lines of the Mooney plot would be non-linear. More precisely, they would show an upward convexity, especially at higher values of the slit gap height. This has some consequences on the choice of the slit or capillary size in order to obtain accurate measurement of rheological data.

Wednesday 15:40 Ulisse

NF12

Yielding, wall-slip and instability, of yield stress fluids in “true” elongation (experiments)

Xiao Zhang¹, Rakshith Shetty², Oumar Fdoul³, Élise Lorenceau⁴, and Philippe Coussot⁵

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So far, yielding and flow properties of soft-jammed systems (yield stress fluids, YSF) have only been studied from simple shear, and then extrapolated to other flow situations. In particular, simple flows such as elongations have barely been investigated experimentally or only in a non-constant, partial volume of material, since usually, extending a fluid sample leads to a separation in two conical parts or to fingering. We show that using smooth tool surfaces makes it possible to remove this problem and obtain a prolonged elongational flow over a large range of aspect ratios in the whole volume of material. The normal force, measured under such conditions, for various soft-jammed systems with different microstructures show that the ratio of the elongation yield stress to the shear yield stress is larger (by a factor around 1.5) than expected from the standard theory for YSF which assumes that the stress tensor is a function of the second invariant of the strain rate tensor [1]. This suggests that the constitutive tensor of such materials cannot be determined solely from macroscopic shear measurements, and this implies that the tensorial form of the constitutive equation for YSF should rely on a yielding criterion differing from the simple von Mises criterion. This experiment also allows to characterize wall slip properties during an elongational flow of the bulk. It appears that the apparent thickness of the sheared liquid layer (along the wall) is much larger (by almost two orders of magnitude) than that observed in simple shear [2]. This suggests that wall slip properties strongly depend on the flow characteristics in the bulk. At last we show that attempting to obtain a 2D elongational flow, by injecting air at the center of a fluid sheet between two smooth plates, systematically leads to an instability. This confirms that the fluid mechanics of YSF in elongation is a complex field which needs to be further explored.

[1] X. Zhang et al., submitted (2017) [2] X. Zhang et al., Phys. Rev. Lett., in press, 2017

Wednesday 16:30 Ulisse

NF13

Diving into a shear-thickening bath

Philippe Bourrienne¹, Caroline Cohen², Robert E. Cohen³, and Gareth H. McKinley¹

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³Chemical Engineering, MIT, Cambridge, MA, United States

Shear-thickening fluids, formulated from high volume fraction suspensions of micro or nanoparticles, react to imposed excitations with a tunable behavior. At low shear rates, they flow like a Newtonian or weakly shear-thinning liquid, whereas they rapidly stiffen following a more rapid perturbation. When a solid object impacts a bath of shear-thickening fluid, the initial velocity determines the different settling regimes that are observed. We will describe these different regimes with regard to the rheological properties of the shear-thickening liquid and the characteristics of the impacting object. A few surprising observations could be noticed. First, a high velocity is not always the best way to penetrate such suspensions. Under such conditions, an appropriately-shaped fast-moving object can also bounce during the impact due to the shear-thickening behavior. For those objects that do penetrate the liquid, the sedimentation process may also be discontinuous or exhibit aperiodic oscillations due to dynamical interactions between the timescale characterizing the rate of shear-thickening and the inertia of the sedimenting particle.

Wednesday 16:50 Ulisse

NF14

Molecular dynamics simulations of shear-thickening behaviour using a configurational thermostat

Calum M. Williams, Mark Haw, and Leo Lue

Chemical and Process Engineering, University of Strathclyde, Glasgow G1 1XJ, United Kingdom

We investigate shear thickening in the flow of simulated concentrated particle suspensions, comparing the effect of 'thermostatting' positional vs velocity degrees of freedom, to explore how shear thickening may depend on or generate deviations from the linear flow profile [1]. Traditionally when performing non-equilibrium molecular dynamics (NEMD) simulations a velocity drag term, known as a kinetic thermostat, is introduced to the equations of motion to maintain a constant system temperature. An alternative method is the configurational thermostat [2] which modifies the positional equation of motion of the particles mimicking the influence of an interstitial fluid. Thermostatting the positional instead of the velocity degrees of freedom has the advantage of requiring no previous knowledge of or making any assumption about the streaming velocity. We perform NEMD simulations of a sheared simple fluid (WCA fluid), comparing results where different definitions of the system temperature (i.e. kinetic or configurational temperature) are thermostatted. Through Fourier analysis of particle velocities for the configurational thermostat simulations we observe a secondary flow regime which is oscillatory in nature and apparent in the shear-thickening regime. This secondary flow regime is only observable when using the configurational thermostat implying that it is the allowed deviations in velocity from the linear flow profile that leads to shear-thickening for this system. We also explore the effect of the thermostat choice on the liquid structure and make comparison between the configurational thermostat term in the equations of motion and hydrodynamic forces common in molecular dynamics simulation of sheared suspensions.

[1] Delhommelle, J. et al. (2004). The Journal of chemical physics, 120(13), 6117-6123. [2] Lue, L. et al. (2002). Molecular Physics, 100(14), 2387-2395.

Wednesday 17:10 Ulisse

NF15

Inline settling of particles in a Bingham Fluid

Emad Chaparian¹, Anthony Wachs², and Ian A. Frigaard¹

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In Stokes flow of a particle settling within a yield stress fluid, the resistive force of the yield stress must be overcome in order for the particle to move. This leads to a critical ratio of the buoyancy stress to the yield stress: the yield number. This translates geometrically to a critical envelope around the particle in the limit of zero flow, that contains both the particle and encapsulated unyielded fluid. Such unyielded envelopes and critical yield numbers are becoming well understood for single (2D) particles, as well as the means of calculating [1, 2]. Here we study multiple particles, which introduces interesting complications. Firstly, plug regions can appear between the particles and connect them together, depending on the proximity. The combination forms larger (and heavier) particle with a different yielding behaviour. Thus, small particles (that cannot move alone) can be pulled by larger particles. Increasing the number of particles leads to "necklaces" of particles, which can have interesting chain dynamics, including breaking and reforming.

[1] Chaparian, E., & Frigaard, I. A. (2017). Journal of Fluid Mechanics, 819, 311-351. [2] Chaparian, E., & Frigaard, I. A. (2017). Journal of Non-Newtonian Fluid Mechanics, 243, 47-55.

Wednesday 17:30 Ulisse

NF16

Hydrodynamic instabilities in displacing a viscoplastic fluid with a Newtonian fluid

Marjan Zare and Ian A. Frigaard

Mechanical Engineering, University of British Columbia, Vancouver, Canada

We study miscible displacement of a heavy viscoplastic fluid with a light Newtonian fluid against gravity direction. For sake of simplicity, we consider displacement flow in a plane-channel and the idealized Bingham model for the rheology of displaced fluid. The flow is governed by Re , Bn , m , X , representing inertia, plastic stresses, viscosity ratio and buoyancy force respectively. To tackle the nonlinear character of the constitutive equations, Augmented-Lagrangian method is applied for numerical simulations. Flow regimes are quantified in $(Re, X/m)$ - plane as stable, unstable, symmetric and asymmetric. The results indicate that the same flow regimes are present at higher Bn , however, these fluids are globally more energy stable such that the threshold of instabilities are higher. In the other words the onset of instability is delayed. Four famous types of instabilities including Bamboo, inverse Bamboo, Rayleigh-Taylor, Kelvin-Helmholtz are observed and are delineated in (m, X) plane for each Bn . In the case of stable displacement, speed of front is compared with one of steady traveling wave. It is confirmed that the flow can be fully dispersive, develops a spike ahead of the main front or have a steady uniform front. In addition, we use lubrication model and analyze the interface motion. The interface profiles are derived and presence of a shock using kinematic wave theory is investigated. There is a good agreement between displacement front behavior obtained from 2-D computations and theoretical analysis. We demonstrate that wall layers can be static and moving, while mobile layers either evolve to become static or are washed from the channel at long times. The dynamic of residual layer on the wall can be predicted from displacement front behavior using the technique presented earlier in Zare, M, et al (2017).

Wednesday 17:50 Ulisse

NF17

Experiments on obstructed viscoplastic flow in a thin slot

Masoud Daneshi¹, Mark Martinez¹, Neil J. Balmforth², Duncan R. Hewitt³, and Jordan MacKenzie¹

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²Department of Mathematics, University of British Columbia, Vancouver, Canada; ³Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, United Kingdom

The specific problem under consideration in this work is the flow of a viscoplastic fluid around obstacles placed in a Hele-Shaw cell, which is the simplest possible idealization of how a spatial non-uniformity in a slender conduit can block flow. During the first phase of this study, the flow of Carbopol around a cylindrical obstacle placed in a Hele-Shaw cell is investigated. The walls of the cell are chemically treated to minimize any slip of the Carbopol over their surfaces (which is independently confirmed by a PTV-OCT technique specially designed to examine the degree of wall slip). Particles seeded in the flow are used for visualization, exploiting either micro-Particle-Image-Velocimetry or image statistics. These visualizations confirm that fluid is swept around the edges of the blockage leaving stagnant plugs attached to the front and back of the cylinder. The lengths of the fore-aft plugged regions are measured as functions of flow rate and fluid rheology. The theoretical results obtained based on an Augmented-Lagrangian technique show the same trend for plug length with respect to parameters corresponding to the rheological properties of the fluid. Despite the theoretical findings, however, the plug at the front of the obstacle is found to be systematically larger than that at the rear. The effect of wall-slip and sharp radius of curvature at the leading and trailing edges of the obstacle are also considered in relation to the shape and size of the static yielding surfaces. In the second phase of this work, the hydrodynamic interactions of the obstacles are studied by examining the flow around two obstacles placed in the slot at different orientations. The results show that the obstacles interfere more effectively with the flow, when they are aligned with the incident flow direction than they are normal to it. In the case of the parallel arrangement, a large stagnant region forms between the obstacles that bridges the gap between them and leads to significant channelization of the flow.

Symposium SM

Polymer Solutions & Melts

Organizers: Yuichi Masubuchi, Angel Moreno and Daniel Read

Wednesday 14:20 Tritone

SM7

A novel criterion for brittle fracture of entangled polymer liquidsManfred H. Wagner¹, Esmaeil Narimissa¹, and Qian Huang²¹*Polymer Engineering and Physics, TU Berlin, Berlin D-10623, Germany;* ²*Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kongens Lyngby DK-2800, Denmark*

A physical explanation for the deterministic brittle fracture of entangled polymer solutions and melts is presented: crack initiation follows from rupture of primary C-C bonds, when the strain energy of an entanglement segment reaches the energy of the covalent bond. Thermal fluctuations lead to a short-time concentration of the strain energy on one C-C bond of the entanglement segment, and the chain ruptures. This limits the maximum achievable stretch of entanglement segments to a critical molecular stretch of approximately 6. As fracture is caused by thermal fluctuations, we call this "entropic" fracture, in contrast to the "enthalpic" fracture model, which assumes that chains will only rupture when they are fully stretched and the rupture force of a C-C bond is reached. Recent experimental data of Huang et al. [1] and Huang and Hassager [2] on fracture of solutions of nearly monodisperse polystyrenes dissolved in oligomeric styrene and of a well characterized polydisperse polystyrene melt, are in general agreement with the entropic fracture criterion. For quantitative agreement, finite extensibility effects have to be considered.

[1] Huang, Q. et al. (2016). Physical review letters, 117(8), 087801. [2] Huang, Q., & Hassager, O. (2017). Soft matter, 13(19), 3470-3474.

Wednesday 14:40 Tritone

SM8

Molecular conformation of star polymers in nonlinear extensional flow followed by relaxation in small angle neutron scatteringAnine L. Borger¹, Kell Mortensen¹, Qian Huang², Ole Hassager², Kristoffer Almdal³, Jacob Kirkensgaard¹, and Chris Garvey⁴

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Entangled melts of branched polystyrene behave like linear polystyrene in the steady state of fast extensional flow as was shown experimentally and theoretically by Huang et al. [1] and Ianniruberto and Marrucci [2]. It is proposed in [2] that the physical origin of this behavior is that the branched molecules become quasi-linear in shape due to arm withdrawal and alignment. In [1] the stress relaxation of a symmetric star was found to be similar to that of a linear molecule with the same backbone length at short and intermediate times. At long times they differ however, but both are well described by the DE-prediction. The difference is proposed to be due to the branch point in the star molecule.

We investigate the molecular conformation, using small angle neutron scattering, of symmetric star molecules for a range of extensional strain rates and the stress relaxation following extensional flow for one of the rates. The extensional rheology of the samples was measured on a Filament Stretch Rheometer, and the samples were quenched for subsequent neutron scattering. We work with two complimentary samples: In the first sample, some stars are fully labeled to gain information on the overall molecular conformation and in the second sample only the ends are labelled to gain information on their correlations. By combining small angle neutron scattering datasets for these two samples, we look into the propositions on the quasi-linearity and branch point affecting the relaxation.

[1] Huang, Q. et al. (2016). Macromolecules, 49(17), 6694-6699. [2] Ianniruberto, G., & Marrucci, G. (2012). Macromolecules, 46(1), 267-275.

Wednesday 15:00 Tritone

SM9

Rheological properties of model comb polystyrenes with entangled and unentangled side chainsMahdi Abbasi¹, Lorenz Faust², and Manfred Wilhelm³¹*Engesserstr. 18, Karlsruhe Institute of Technology, ITCP, Karlsruhe, Baden-Württemberg 76131, Germany;*²*Engesserstr. 18, Karlsruhe Institute of Technology, ITCP, Karlsruhe, Baden-Württemberg 76131, Germany;*³*Engesserstr. 18, Karlsruhe Institute of Technology, ITCP, Karlsruhe, Baden-Württemberg 76131, Germany*

Monodisperse comb polystyrenes (comb-PS) with loosely to densely-grafted architectures up to loosely-grafted bottlebrush structures were synthesized via anionic polymerization. These comb-PS were categorized in two different series with respect to the length of the side chains. Nearly monodisperse comb-PS series with entangled side chains $M_{w,br}=44$ kg/mol had the same backbone $M_{w,bb}=290$ kg/mol. The comb-PS series with unentangled side chains $M_{w,br}=8$ kg/mol had a backbone $M_{w,bb}=400$ kg/mol. In both series the number of side chains was systematically changed and linear and extensional rheological properties was tracked. Within these samples we distinguished how number of branches or distance between two neighbor branch points change the zero shear viscosity according to the linear counter parts. These samples were categorized to loosely grafted combs, densely grafted comb and nearly loosely grafted bottlebrush conformations. Strain hardening properties of these comb-PS series in extensional deformations were also quantified and correlated to the branch length as well as number of branches per molecule.

Wednesday 15:20 Tritone

SM10

Exploring the dependence of polymer architecture on rheology

Jeppe Madsen, Qian Huang, and Ole Hassager

Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

Polystyrene is arguably the most common polymer used in the study of polymer flow properties. Apart from being thermoplastic, polystyrene is a non-crystalline polymer with a glass transition temperature of around 100 °C. It is therefore easy to 'lock' any internal structure induced in the polymer melt by rapid cooling to room temperature. Furthermore, linear polystyrenes of essentially any degree of polymerisation and a wide range of molecular weight distributions are commercially available. Well-defined polystyrenes can be prepared by anionic polymerisation, a conceptually simple but synthetically demanding method [1]. We are interested in the rheology and internal structure of polystyrenes with complex architectures. Polymers with complex structures can be synthesised using anionic polymerization [2]. However, we have found that building a library of structurally related complex polymer structures that primarily varies in terms of molecular weight is highly time-consuming when using this technique alone and this severely delays thoroughly methodical studies of flow properties. We are therefore developing methods for rapid preparation of high molecular weight polystyrenes with complex architectures by using a combination of anionic polymerisation and modern polymerisation techniques based on controlled radical polymerisation. Due to termination reactions in controlled radical polymerisation, such polymers often come out with a larger polydispersity than corresponding polymers made solely by anionic polymerisation. Here we present our approach to preparing complex polystyrene architectures. In addition, examples of the implications of the molecular weight distribution on linear and non-linear rheology are discussed.

[1] Ndoni, S. et al. (1995). Review of scientific instruments, 66(2), 1090-1095. [2] Hadjichristidis, N., & Hirao, A. (Eds.). (2015). Anionic polymerization: principles, practice, strength, consequences and applications. Springer.

Wednesday 15:40 Tritone

SM11

Understanding and classifying thermorheological complexity for linear and branched polyolefins

Florian J. Stadler

College of Materials Science and Engineering, Shenzhen University, Shenzhen, China

Thermorheological complexity in polyolefins has been reported many times but so far it has not been systematically investigated. Here, a classification of the different types of thermorheologically complex behavior is proposed, which categorize the available data in 5 different types and describe key characteristics. These definitions are based on polyethylene, but other polymers show similar patterns for materials with comparable branching structure. Linear materials are thermorheologically simple as long as many very long short chain branches do not introduce phase separation. Sparsely branched materials show the most significant thermorheological complexity, with significant shape changes of rheological functions with temperature, while higher amounts of branching (such as trees or combs) reduce thermorheological complexity and increase E_a at the same time. Low density polyethylene shows a significant modulus shift at different temperatures probably due to excessive low molecular components.

Wednesday 16:30 Tritone

SM12

Entangled double-stranded and single-stranded DNA soft gels under LAOS: nonlinearity and shear-banding instability

Thomas B. Goudoulas, Sharadwata Pan, and Natalie Germann

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The dynamics and flow properties of DNA, the blueprint of life, are of great significance for understanding its functionality as well as for setting up new technologies. Processing flows typically imply large-scale deformations. Under such conditions, flow instabilities like shear banding may occur and affect the final structure of the product. In this talk, we discuss the general nonlinear properties and shear-banding instability of 115 kilobase pairs (kbp) double-stranded (ds) and 50 kbp single-stranded (ss) DNA dissolved in 75 wt.% glycerol under high salt conditions. Oscillatory shear tests were carried out at small and large amplitudes, and instantaneous velocity profiles were simultaneously measured using a custom-made particle image velocimetry (PIV) setup [1]. The large amplitude oscillatory (LAOS) data was analyzed qualitatively by Lissajous plots, and quantitatively in terms of Chebyshev polynomials. The ds DNA shows intracycle strain stiffening and shear thinning behaviors during elastic and viscous decomposition, respectively. This is in contrast to the intracycle strain softening behavior of concentrated PAAm solutions [2]. In contrast, the ss DNA exhibits initial intracycle strain stiffening at lower strains. This is followed by a transition region, where the elastic and viscous contributions are quantitatively similar, and a terminal high-velocity flow regime. The local minimum of the loss modulus observed in the standard frequency sweeps mimics the response of the wormlike micelles. While the PIV data show discrete strain-driven shear bands for the ds DNA, the ss DNA only forms weak shear bands even at the maximum strain amplitude. The results from this work are insightful from a traditional bulk rheological as well as single molecular perspectives.

[1] Goudoulas, T.B., Pan, S., Germann, N., Polymer (2017) Under review. [2] Goudoulas, T. B. et al. (2017). Journal of Rheology, 61(5), 1061-1083.

Wednesday 16:50 Tritone

SM13

Modeling the kinetics and rheology of thermo-mechanically degraded LDPE

Jerome Simons and Jaap Den Doelder

Physical Chemistry, Chemical Engineering and Chemistry, TU Eindhoven, Eindhoven, The Netherlands

Highly-branched low-density polyethylene (LDPE) is characterized with triple-detector gel permeation chromatography (TD-GPC), dynamic mechanical spectroscopy (DMS), and uniaxial extension rheometry. A representative set of branched polymer molecules is created that matches the measured molar mass distribution and mass-dependent intrinsic viscosity (a long-chain branching indicator). Simultaneously, the molecular ensemble is tuned to match storage and loss modulus, as well as strain hardening, using branch-on-branch rheology simulations. Sensitivity of the rheology predictions to topology choices while satisfying the TD-GPC

results is explored. The optimized molecular ensemble is used as starting point to kinetically simulate thermo-mechanical degradation of LDPE in high-temperature extrusion. The predicted structure and rheology of the degraded polymer is compared with experimental results on similarly degraded polymers. This approach connects mesoscopic simulations to practical polymer processing and quantifies LDPE recyclability options.

Wednesday 17:10 Tritone

SM14

Melt rheology of ring poly(ethylene oxide) melts and comparison with experimental data

Dimitrios G. Tsalikis¹, Loukas D. Peristeras², and Vlasios G. Mavrantzas³

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Atomistic simulations of ring polymer melts have been very useful in elucidating many of the salient features of this special class of polymers [1]. In conjunction, in particular, with a detailed geometric analysis, they have helped successfully address topological interactions in these systems developing due to ring-ring threading or to ring threading by linear chain contamination and their connection with the slow relaxation modes [2]. Here, we extend these efforts to nonequilibrium conditions. We have developed an efficient nonequilibrium molecular dynamics algorithm (NEMD) which has enabled the direct computation of the rheological properties of ring polyethylene oxide (PEO) melts in shear flow. All flow simulations have been performed with LAMMPS [3] using the p-SLLOD equations of motion [4]. The NEMD predictions for the relevant viscometric functions (shear viscosity, first and second normal stress difference) have been analyzed as a function of PEO molecular weight and applied shear flow. They have also been compared against recently measured experimental data [5] for highly purified ring melts. An additional comparison with the rheological behavior of the corresponding linear counterparts will also be presented. Selected configurations from the NEMD trajectories have been subjected to a detailed geometrical analysis [2] to investigate the effect of flow on ring-ring threading events.

[1] Tsalikis, D. G. et al. (2017). *Macromolecules*, 50(6), 2565-2584. [2] Tsalikis, D. G. et al. (2016). *ACS Macro Letters*, 5(6), 755-760. [3] Plimpton, S. (1995). *Journal of computational physics*, 117(1), 1-19. [4] Baig, C. et al. (2005). *The Journal of chemical physics*, 122(11), 114103. [5] Doi, Y. et al. (2015). *Macromolecules*, 48(9), 3140-3147.

Wednesday 17:30 Tritone

SM15

Tube theory modelling for the linear rheology of polydisperse linear polymers

Chinmay Das, Victor Boudara, and Daniel J. Read

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The role of constraint release in determining the relaxation of polydisperse linear polymers remains a topic of active research. The terminal relaxation pathway of the longest species depends sensitively on the relative molar masses and the volume fractions of the other components. While a number of studies have been devoted to the same problem, we believe that a quantitative model that predicts the rheological responses of arbitrary blends of linear polymers is still missing. In this work, we show that the arm fluctuation is always faster in the fattest available tube. We generalize the picture of reptation in fat tube, with the friction determined by constraint release [1], for arbitrary blends of linear polymers. From a stochastic sticky-Rouse model simulation [2] we show that the constraint release contribution to stress initially decays faster than the asymptotic Rouse model prediction. We combine all the new ingredients in a numerical model and show that the predictions agree with a large number of rheological/dielectric experiments on monodisperse, bi-disperse and polydisperse polymers.

[1] Viovy, J. L. et al. (1991). *Macromolecules*, 24(12), 3587-3596. [2] Baxandall, L. G. (1989). *Macromolecules*, 22(4), 1982-1988..

Wednesday 17:50 Tritone

SM16

Nonlinear shear behavior in binary blends of linear polymers with well-separated molecular weights

Hamid Taghipour¹ and Evelyne Van Ruymbeke²

¹*IMCN-BSMA, Université catholique de Louvain, Louvain-la-Neuve, Walloon Brabant-Ottignies 1348, Belgium;*

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Predictions of the Doi-Edwards-Marrucci-Grizzuti (DEMG) [1] and the Graham-Likhtman-McLeish-Milner (GLaMM) [2] models are compared with to the systematic rheological data set in startup shear experiments of steady shear in the nonlinear shear-rate regime for a series of polystyrene solutions, with wide concentration varying range between 2% and 100% (melt state). Both the DEMG and GLaMM models are the most recent version of "tube" theory for entangled polymer melts and solutions includes all, chain stretch, chain retraction, reptative, thermal and convective constraint-release effects. Under strong shear flow, both models can capture the non-linear transient response (stress overshoots) quite well. However, several differences appear between the two models, that we investigate in order to understand their origin. In particular, it is observed that the magnitude of the stress overshoots predicted by the DEMG model are more pronounced compared to the GLaMM model, which is in better agreement with our experimental results. We also study the influence of should first comment that the adjustable parameters (i.e. entanglement density, plateau modulus, etc.) as well as of their relevant numerical prefactors used in order to determine for the different characteristic times on the theoretical transient viscoelastic response of these materials. constants that appear in these models (i.e. t_d, t_R) will become significant to correctly describe the nonlinear data, that go into the theories.

[1] Marrucci, G. (1988). *Gazz. Chim. Itali.*, 118, 179-185. [2] Graham, R. S. et al. (2003). *Journal of Rheology*, 47(5), 1171-1200.

Symposium MN

Micro, Nano Fluidics & Microrheology

Organizers: Nikolai Denkov, Sehyun Shin and Manlio Tassieri

Wednesday 14:20 Nettuno 1

Keynote MN8

Differential dynamic microscopy microrheology: frequency-dependent moduli without tracking!Paolo Edera¹, Davide Bergamini¹, Véronique Trappe², Fabio Giavazzi¹, and Roberto Cerbino¹¹*Biometra Department, University of Milan, Segrate, MI 20090, Italy;* ²*Department of Physics, University of Fribourg, Fribourg, Switzerland*

Particle tracking microrheology (PT- μ r) exploits the thermal motion of tracer particles to probe the local mechanical properties of soft materials. Despite its appealing conceptual simplicity, PT- μ r requires calibration procedures and operating assumptions that constitute a practical barrier to a wider adoption, especially in industrial environments. Here, we present a novel approach to microrheology [1] that exploits Differential Dynamic Microscopy (DDM) [2, 3]. DDM-based microrheology (DDM- μ r) provides a tracking-free approach based on the multi-scale, temporal correlation study of the image intensity fluctuations that are observed in microscopy experiments as a consequence of the motion of the tracers. We describe DDM- μ r experiments performed with both simple and viscoelastic fluids, seeded with tracer particles of different size and concentration. Our results agree with PT- μ r when the latter can be used, with the benefit of a calibration-free, completely automated, operator-independent and unbiased image processing procedure. In addition, DDM- μ r is found to provide reliable information even in cases where PT- μ r is not a suitable option, because the tracers are too small or too crowded to be tracked accurately or because the rotational degrees of freedom of the probe particles are of interest [4]. Our findings suggest that DDM- μ r can be a viable alternative and complement to PT- μ r and to other rheological probes.

[1] P. Edera, D. Bergamini, V. Trappe, F. Giavazzi, R. Cerbino, under review in *Phys. Rev. Materials* (2017). [2] Cerbino, R., & Trappe, V. (2008). *Physical review letters*, 100(18), 188102. [3] Cerbino, R., & Cicuta, P. (2017). *The Journal of Chemical Physics*, 147(11), 110901. [4] Giavazzi, F. et al. (2016). *Journal of Physics: Condensed Matter*, 28(19), 195201.

Wednesday 15:00 Nettuno 1

MN9

Investigating the viscoelastic properties of complex materials and cells to study cancer migrationLouise M. Mason¹, Manlio Tassieri¹, Raymond Ogden², Michael F. Olson³, and Huabing Yin¹¹*Biomedical Engineering, University of Glasgow, Glasgow, United Kingdom;* ²*Mathematics and Statistics, University of Glasgow, Glasgow, United Kingdom;* ³*Cancer Research UK Beatson Institute, Glasgow, United Kingdom*

One of the most destructive characteristics of cancer is metastasis; the ability of primary tumour cells to migrate to form secondary tumours in the body. The biochemical aspects of cancer metastasis have been well studied, however, the contribution of cell mechanics to cancer invasion remains largely unexplored. Recently, the importance of the mechanical properties of cells in pathological conditions has been increasingly recognized, imposing a need of advanced cell microrheology measurements. Atomic force microscopy (AFM) has been established as a powerful tool for measuring the mechanical properties of cells under physiological conditions with nanoscale precision. Previously, work has shown that cancer cells can have altered stiffness values relative to healthy cells, however, its implementation in measuring dynamic viscoelastic properties is time-consuming and beset with complex model fitting. We developed a novel AFM-microrheology approach for educing the linear viscoelastic properties of a range complex materials and living cells, over a wide range of frequencies based on a stress-relaxation nanoindentation. The AFM experimental data was directly analysed without the need for preconceived viscoelastic models. The method has been validated by measuring the known complex materials, and the results show good agreement with conventional oscillatory bulk-rheology measurements. Using this capability, an investigation into drug response of breast cancer cells was undertaken. By measuring the elastic ($G'(\omega)$) and the viscous ($G''(\omega)$) moduli of living cells, we discover, for the first time in literature, characteristic transitions of the tangent ($G''(\omega)/G'(\omega)$) that indicate the capability of cell restructuring and migration. This approach gives the opportunity to gain new insights into mechanical properties of soft matter without using preconceived models. Our method could be implemented in conventional AFM setups, providing a powerful tool to measure dynamic mechanical properties of cells.

Wednesday 15:20 Nettuno 1

MN10

Microrheology of biofluidsElke Bradt¹, Sabine Hild¹, Erwin K. Reichel², Thomas Voglhuber – Brunnmaier², and Milan Kracalik¹¹*Institute of Polymer Science, Johannes Kepler Universität Linz, Linz, Austria;* ²*Institute of Microelectronics and Microsensors, Linz Institute of Technology, Linz, Austria*

Rheology of biofluids introduces a new inside into medical technology and is crucial for the associated physiological function. Typical example for biofluids is synovial liquid, which can be found in joints. The viscosity and elasticity of synovial fluids are essentially determining the ability to maintain the joint spacing, reduce slip resistance, and protect cartilage from abrasion. Biological elastic liquids show pronounced extensional viscosity, they are therefore often analyzed using capillary breakup rheometry. Comparing to this method microrheological investigation e.g. passive microrheology based on dynamic light scattering is in the meantime a common technique using commercial equipment. In order to be conform with actual ethics in medicine research, for preliminary studies (optimization of measuring conditions like tracer selection, temperature, pH) model liquids are important. In this work different model liquids, which are physiologically similar to synovial liquid, have been explored and measured using passive microrheology. The differences in viscoelastic behavior between model liquids and synovial liquid were evaluated.

Wednesday 15:40 Nettuno 1

MN11

Polymer-polymer interaction in a flow measured by a scanning probe microscopy

Ruri Hidema, Seika Hayashi, Yoshiyuki Komoda, and Hiroshi Suzuki

Department of Chemical Science and Engineering, Kobe University, Kobe, Hyogo 657-8501, Japan

Addition of little amount of polymers to Newtonian flow changes fluid properties drastically. Drag reduction, elastic instability, sudden increase of extensional viscosity of the fluids are typical examples. In such a polymer solution, it is considered that the polymers interact with each other in the flow, or polymers interact with flow. Such interactions should affect the fluid characteristics. In this study, we have tried to measure interactive force between polymer and polymer in flows, and between polymer and flows directly using a scanning probe microscopy (SPM). Polyethyleneglycol (PEG, $M_w=20,000$) and methoxy polyethyleneglycol thiol that is a linear PEG with a free thiol group at one end (mPEG-SH, $M_w=20,000$) were prepared as polymers. Glycerol was also used to control the flow viscosity. A small flow channel connected to a syringe by tubing was settled in the SPM. The syringe was filled with sample solutions. A syringe pumps controlled flow rates of sample solutions in the small channel. Velocity fields in the channel were measured by a particle tracking velocimetry. First, a gold-coated cantilever was dipped in mPEG-SH solution in order to attach the thiol group to the cantilever. Second, the cantilever carrying mPEG-SH was dipped in the flow of a glycerol solution or a PEG solution. When the fluid was a glycerol solution, the drag coefficient measured by SPM was a function of Reynolds numbers, which was not affected by the glycerol concentration. On the other hand, when the flow was a PEG solution, the drag coefficient was higher than that of a glycerol solution at the same Reynolds number. That depended on the PEG concentration. Therefore, we consider that interactive force between mPEG-SH attached to the cantilever and PEG in the flow was measured in the present method. We believe the direct measurement proposed in the present study is quite unique and promising to study polymer-polymer interactions in flows and polymer-flow interactions.

Wednesday 16:30 Nettuno 1

MN12

Viscosity of a DNA transient network: Newtonian to shear thinning transitionTommaso Bellini¹, Giovanni Nava¹, Valerio Vitali², Tie Yang², Paolo Minzioni², Roberto Osellame³, Francesca Bragheri³, and Ilaria Cristiani²¹*Dept. of Medical Biotechnology and Translational Medicine, University of Milano, Milano, Italy;* ²*Dept. of Electrical, Computer and Biomedical Engineering, University of Pavia, Pavia, PV 27100, Italy;* ³*Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche, Milan, MI 20133, Italy*

The complex dynamic response of reversible gels and semi-diluted polymer solutions is notoriously articulated and its study can benefit a lot from the presence of model systems where crucial parameters (e.g. control of geometry, mesh size, binding strengths, bond lifetimes) could be finely controlled. We recently introduced a system of DNA particles shaped as nano-stars (NS) that can interact via Watson-Crick pairing thanks to the presence of sticky points on the tip of their arms. The system was designed so that, when the temperature (T) is lowered below a point T^* , the system continuously freezes into an hydrogel without incurring in phase transitions [1, 2]. We performed micro-rheology measurements via optical shooting by using a custom made optofluidic chip [3]. The device consists in a straight microchannel glass chip in which facing waveguides can deliver a controlled optical force to a PMMA bead and shoot it across the channel. By studying the motion of the bead as a function of the optical force, we could determine the viscous properties of the hydrogel across the gelation transition. At higher T the system is Newtonian, as expected for a suspension of independent nanocolloids. Upon cooling the system, in a temperature range of 10 °C, the system reversibly and continuously transforms into a strong shear-thinning fluid, passing through a set of intermediate states where it behaves as a power-law fluid. We demonstrate that the whole behavior can be predicted from the topology of the network and the bond free energy.

[1] Biffi, S. et al. (2015). *Soft Matter*, 11(16), 3132-3138. [2] Biffi, S. et al. (2013). *Proceedings of the National Academy of Sciences*, 110(39), 15633-15637. [3] Yang, T. et al. (2016). *Scientific reports*, 6, 23946.

Wednesday 16:50 Nettuno 1

MN13

Chiral micro-particles interacting with viscous shear flowsFrancesca Tesser¹, Marine Daëffl¹, Alfred J. Crosby², Justine Laurent¹, Olivia Du Roure¹, and Anke Lindner¹¹*PMMH, ESPCI Paris, Paris, France;* ²*Department of Polymer Science and Engineering, University of Massachusetts Amherst, Amherst, MA, United States*

The motion of an anisotropic particle in a viscous fluid inherits complexity from its shape and eventual deformability. One particular example of a complex shape is a chiral geometry, as found in micro-helices. This specific form is commonly found in nature in flagellated swimmers and it is also deployed in micro-robots. Rigid helices under shear flow are known to be subject to migration across streamlines, but little is known on the precise dynamics or the role of flexibility. In our study we fabricate well-controlled micro helices by different techniques, by means of a micro-printer or by synthetically fabricated ribbons, which can spontaneously coil into a helical structure [1]. We then perform experiments by releasing these micro-objects individually in confined microfluidic channels to investigate their dynamics under shear flow and in the proximity of boundaries. The understanding of the dynamics of individual particles can serve as a basis for future studies on suspensions of chiral micro-particles.

[1] Pham, J. T. et al. (2013). *Advanced Materials*, 25(46), 6703-6708.

Wednesday 17:10 Nettuno 1

MN14

Viscoelastic Poiseuille flow through wavy-wall microchannelsSimon J. Haward¹, Jacob Page², Tamer A. Zaki³, and Amy Q. Shen¹¹Okinawa Institute of Science and Technology, Onna-son, Okinawa 904-0495, Japan; ²School of Mathematics, University of Bristol, Bristol BS8 1TW, United Kingdom; ³Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD 21218, United States

We examine the flow of Newtonian fluids and viscoelastic polymer solutions through rectilinear microchannels with one smooth and one wavy wall bounding the channel depth. Channels are precision fabricated in fused silica by selective laser-induced etching, providing high spanwise width (w) to depth (d) ratios and small wave amplitudes $A \ll d$. Various channels are tested with dimensionless depths in the range $0.6 < a = 2pd/\zeta < 10$, where ζ is the roughness wavelength. Dilute polymer solutions are formulated from high molecular weight poly(ethylene oxide) in aqueous solvents of varying viscosity. This provides fluids with a wide range of rheological properties, specifically elasticity numbers in the range $0.001 < El = (1-\beta)Wi/Re < 44$, where β is the solvent-to-total viscosity ratio, Wi is the Weissenberg number and Re is the Reynolds number. Micro-particle image velocimetry is employed to measure the flow fields for the various fluids within the microchannels as we increment $0 < Wi < 50$ and $0 < Re < 500$. In all cases we observe that the wavy wall causes small perturbations ($\sim 5\%$) to the Poiseuille base flow. However, there is a subtle interplay between El , the magnitude of a , and the imposed flow conditions, that together affect the shape of the perturbation and the depth of its penetration into the channel, P . Of chief interest is the support of our experiments for recent theoretical predictions of a 'critical layer' within the channel, located at a dimensionless depth S , which depends on El [1]. Our new experimental results for viscoelastic Poiseuille flow over wavy surfaces are consistent with the existence of three broad flow regimes [1], classified as "shallow-elastic", "deep-elastic" and "transcritical", that can be summarized in a phase diagram in a- S parameter space. In the transcritical regime (defined by $a > S$, $S < 1$), a surprising non-local amplification of the perturbation can occur within the critical layer, significantly influencing P .

[1] Page, J., & Zaki, T. A. (2016). Journal of Fluid Mechanics, 801, 392-429.

Wednesday 17:30 Nettuno 1

MN15

Secondary flows of viscoelastic fluids in curved microchannelsLucie Ducloue¹, Laura Casanellas², Simon J. Haward³, Robert J. Poole⁴, Manuel A. Alves⁵, Sandra Lerouge⁶, Amy Q. Shen³, and Anke Lindner¹¹PMMH, ESPCI Paris, Paris, France; ²Laboratoire Charles Coulomb, Université Montpellier II, Montpellier, France; ³Okinawa Institute of Science and Technology, Onna-son, Okinawa 904-0495, Japan; ⁴Mechanical, materials & aerospace engineering, University of Liverpool, Liverpool, United Kingdom; ⁵Department of Chemical Engineering, University of Porto, Porto, Portugal; ⁶MSC, Université Paris-Diderot, Paris, France

The flow of viscoelastic fluids is well-known to develop purely elastic instabilities in curved geometries at low Reynolds numbers [1, 2]. Below the critical shear rate at which the instability is triggered, a steady, secondary flow develops in the cross-section of the channel. The relative strength of this secondary flow increases with the magnitude of the elastic contribution to the flow. For channels of constant curvature with a square cross-section, the secondary flows had so far only been observed numerically [3]: in the absence of inertia, they take the shape of two counter-rotating vortices located in the plane of the channel cross-section. We present the first experimental visualization evidence and characterization of these steady secondary flows. Using a dilute solution of polyethylene oxide, we first capture the nature of the flow by performing confocal imaging of the stream-dyed fluid in the channel cross-section. We show that the observed dye transport is in good qualitative agreement with the flow lines computed numerically. We then use micro-PIV techniques to measure the components of the flow velocity in the plane of the microchannel, half-way between the top and bottom boundaries. We show that the measured streamlines and the relative velocity magnitude of the secondary flows are again in good agreement with the numerical results. This first step in visualizing and quantifying the secondary flows opens up perspectives for controlled and efficient mixing at low Reynolds numbers, as well as a better understanding of the potential link between the secondary flows and the triggering of the elastic instability [2].

[1] Shaqfeh, E. S. (1996). Annual Review of Fluid Mechanics, 28(1), 129-185. [2] Zilz, J. et al. (2012). Journal of Fluid Mechanics, 712, 203-218. [3] Poole, R. J. et al. (2013). Journal of Non-Newtonian Fluid Mechanics, 201, 10-16.

Wednesday 17:50 Nettuno 1

MN16

Steady shear flow behavior of magnetorheological fluids in microchannels

Jose R. Morillas, Keshvad Shahrivar, and Juan de Vicente

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Magnetorheological (MR) fluids are non-Brownian suspensions of magnetisable particles that exhibit a "liquid-to-solid" transition upon the application of external magnetic fields. In the absence of magnetic fields, MR fluids behave as regular Newtonian fluids. However, in the presence of sufficiently large magnetic fields a plastic behaviour is typically described. Recently, a Casson-like Universal Master Curve has been successfully proposed for the description of their bulk rheological properties [1]. In this communication we validate the Universal Master Curve against steady shear data in strongly confined microfluidic flows. Stress-controlled experiments were carried out in glass microchannels (100 μm width) and pressure drop Δp versus flow rate Q curves were obtained under a range of particle volume fractions (up to 5 vol%) and magnetic fields -strengths and gradients- in the linear magnetization regime (up to 100 kA/m). With this, the viscosity curves were computed using the Weissenberg-Rabinowitsch-Mooney equation and compared with Computational Fluid Dynamics Simulations.

[1] Ruiz-López, J. A. et al. (2016). Journal of Rheology, 60(1), 61-74.

Symposium SG

Solids, Glasses, & Granular Materials

Organizers: Philippe Coussot, Joe Goddard and Luigi Grassia

Wednesday 14:20 Nettuno 2-3

SG8

A Cosserat plasticity model for the deformation and flow of granular materials and soils

David Harris

School of Mathematics, University of Manchester, Manchester M13 9PL, United Kingdom

Classical plasticity models for granular materials are limited to quasi-static and steady-state problems. Two such models, non-associated flow rule and double-shearing, are ill-posed (solutions to pure initial value problems are unstable), preventing numerical approximation to solutions for time-dependent problems. Both models successfully describe some aspects of granular material behaviour and a desirable aim for a well-posed model is to retain terms in the equations describing those aspects and to embed them into a new framework for use in a wider variety of contexts. A classical continuum neglects grain spin and whilst sufficient to describe some aspects of the mechanics of granular materials, it is inadequate for others, e.g. in the interior of shear-bands and the immediate vicinity of external boundaries. Grain spin is incorporated using a Cosserat continuum with intrinsic spin interpreted as the average grain spin in a representative volume element. The kinematic quantities (i) difference between the anti-symmetric parts of the velocity gradient and intrinsic spin tensors, (ii) spatial gradient of the intrinsic spin, are associated with the anti-symmetric part of the Cauchy stress and the couple stress tensor. We present a plasticity model in which the classical part incorporates pressure dependent yield and non-associated plastic potential and a term enabling coincidence of stress and velocity characteristics in plane deformations. The model is hyperbolic for planar steady-state flows of a Mohr-Coulomb material. The flow rule equations for the Cosserat quantities complete the constitutive model. A classical flow is such that the intrinsic spin is constant and the model reduces to that of a classical continuum model. For flows in which the intrinsic spin is not constant the classical equations are augmented with the extra quantities and equations appropriate to a Cosserat continuum. We describe the model, discuss some of its more important properties and consider some applications.

Wednesday 14:40 Nettuno 2-3

SG9

Low impact cratering on granular beds under low gravity

Lucas Sardo¹, Florian Thuillet², Patrick Michel², and Rudy Valette¹

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In the context of asteroid material sampling, landers are sent on the asteroid surface, which is made of regolith, that can be considered at first approximation as a granular bed. An important question is to understand the physics that governs the penetration of the lander in the granular bed, for a given impact velocity. For slow impact-induced flows on frictional non-cohesive granular beds on Earth, the soil behaves like a yield-stress fluid, where the yield-stress increases linearly with (depth induced) static pressure, and this rheology governs the penetration flow. However, for vanishing gravity, as encountered on asteroids, one expects dynamic (impact) pressure to dominate the penetration flow dynamics. In this paper, we model regolith as a $\mu(I)$ granular continuum fluid and propose both dimensional analysis and numerical simulations to identify asymptotic and coupled regimes for penetration of an impacting sphere from Earth to vanishing gravities. We find a penetration that scales quasi linearly with impact velocity for Earth gravity, that switch to sublinear for low enough gravities. The role of bed layer thickness and elasticity will be discussed and compared to discrete simulations.

Wednesday 15:00 Nettuno 2-3

SG10

Well-posed continuum equations for granular flow

Thomas Barker¹, J. M. N. T. Gray², David G. Schaeffer³, Michael Shearer⁴, and James Baker⁵

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Dynamic equations for granular flow have been plagued with the issue of ill-posedness, where small perturbations grow at an unbounded rate in the limit that their wavelength tends to zero. This issue hinders numerical calculations as grid-scale noise is always generated, irrespective of the solution method used. The $\mu(I)$ -rheology [1] is well-posed for intermediate values of the inertial number I but is ill-posed for both small and large values [2]. Many flows of practical interest naturally have regions in the ill-posed ranges so numerical simulations lead to grid-dependent, time-limited and ultimately erroneous results. Three major modifications to the $\mu(I)$ -equations have been made which ensure well-posedness. Limiting attention to shallow flows, depth-averaged equations are derived [3]. These capture spatio-temporal perturbations, such as granular rollwaves, and give accurate flow profiles in chutes with frictional sidewalls [4]. For fully two-dimensional transient flows the $\mu(I)$ -rheology can be made well-posed by modifying the dependence of μ on I . This gives a partially-regularised system of equations [5] which are well-posed for all inertial numbers, below a very large upper limit. Similarity to the incompressible Navier-Stokes equations allows many existing numerical methods to be easily used to make reliable predictions of granular flows in truly complex time-dependent scenarios. Small variations in the local solids volume fraction ϕ can strongly affect the strength of a granular material. Another well-posed theory is derived by combining the $\mu(I)$ -rheology with critical-state soil mechanics [6]. This general Compressible I -Dependent Rheology (CIDR) gives a more complete physical description of granular flows when appropriate constitutive laws are specified and is able to capture the vertical variation of ϕ in chute flows.

[1] Jop, P. et al. (2006). *Nature*, 441(7094), 727. [2] Barker, T. et al. (2015). *Journal of Fluid Mechanics*, 779, 794-818. [3] Gray, J. M. N. T., & Edwards, A. N. (2014). *Journal of Fluid Mechanics*, 755, 503. [4] Baker, J. L. et al. (2016). *Journal of Fluid Mechanics*, 787, 367-395. [5] Barker, T., & Gray, J. M. N. T. (2017). *Journal of Fluid Mechanics*, 828, 5-32. [6] Barker, T. et al. (2017). *Proc. R. Soc. A*, 473(2201), 20160846.

Wednesday 15:20 Nettuno 2-3

SG11

High speed confined granular flows down inclines: numerical simulations

Renaud Delannay, Alexandre Valance, and Yajuan Zhu

Institut de Physique de Rennes, Université Rennes 1, Rennes, Bretagne 35042, France

Several works have been devoted to the effect of a lateral confinement on the properties of granular flows. Both experimental and numerical studies have pointed out that frictional lateral walls induce new flow regimes. For example, it has been shown that, at any inclination angle, there is a critical flow rate above which the flow occurs on a static heap, which forms along the base [1]. Flows atop this side wall-stabilized heap (SSH) differ fundamentally from steady and fully developed (SFD) flows on rigid and bumpy bases as they occur over erodible bases. However, they still display SFD features. In a previous study of confined flows on an inclined rigid base [2], we explored extensively and systematically the effect of the variation of the inclination angle and of the mass holdup, for a given value of the gap ($W=68D$ where D is the grain size) between side walls. We observed steady and fully developed flows (SFD flows) up to large angles of inclination where accelerated ones are usually expected. These SFD regimes present non-trivial features, including secondary flows (rolls) and heterogeneous volume fraction, flows with dense core supported by a very agitated dilute layer. Despite the diversity of the features of these states, the mass flow rate obeys a simple scaling law with the flow height. We investigate here the effect of the variation of W on the domain of existence of the SFD flow regimes and on the transition to the SSH regime for decreasing values of W . We also extend the scaling law of the mass flow rate with both the flow height and the gap distance W . Furthermore, we study some properties of the transient accelerating flow observed before reaching the SFD state.

[1] Taberlet, N. et al. (2003). *Physical review letters*, 91(26), 264301. [2] Brodu, N. et al. (2015). *Journal of Fluid Mechanics*, 769, 218-228.

Wednesday 15:40 Nettuno 2-3

SG12

Size segregating intruders in oscillating shear cells

Tomas Trewthella¹, Christophe Ancey¹, and J. M. N. T. Gray²

¹*Environmental Hydraulics Laboratory, École Polytechnique Fédérale de Lausanne, Lausanne, Vaud 1015, Switzerland;* ²*School of Mathematics and Centre for Nonlinear Dynamics, The University of Manchester, Manchester, United Kingdom*

Granular avalanches are prone to segregate particles by size, as a result of gravity forcing and shear-induced dilatation. This mechanical response of the granular media facilitates small particle percolation through gaps (kinetic sieving), after which large particles are squeezed upwards by surrounding small particles (squeeze expulsion). The development of simple continuum models for particle-size segregation has provided a better understanding, nevertheless determining the functional dependence of the segregation rate remains a challenge. In this work we investigate the segregation rate, by running simple shear experiments of bidisperse granular materials. The experimental shear cells consists of two parallel plates that rotate over pivot points to generate an oscillatory shear flow within the granular media. Shear cell configuration has been used extensively to study granular segregation. For the present work, two different shear cells have been used: a 2D and a 3D cell. For the 3D shear cell, we used the refractive index match (RIM) technique for visualizing the intruder. Acrylic spheres, transparent for the substrate and opaque for the intruders, are used in the experiments along with Triton X-100 to achieve the RIM mixture. We ran experiments using single particle intruders immersed in a differently sized medium in both shear cells. Trajectories and local velocities are measured. An estimation of the segregation rate as a function of the size ratio is also obtained for both cells. Size segregation in the 2D shear cell is only observed for large intruders because of the constraints imposed by the planar configuration. In contrast, in the 3D shear cell small particle percolation occurs and it may stop at middle positions in specific cases, while large intruders didn't segregate under certain conditions. These observations raised the question: what is initiating and restraining segregation? Within the presented framework, we suggest the interstitial fluid and size ratio may prevent and restrain segregation.

Wednesday 16:30 Nettuno 2-3

SG13

Compressibility regularizes the $\mu(I)$ -rheology for dense granular flows

Alexandre Valance¹, Renaud Delannay¹, and Joris Heyman²

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The $\mu(I)$ -rheology was recently proposed as a potential candidate to model the incompressible flow of frictional grains in the dense inertial regime. However, this rheology was shown to be ill-posed in the mathematical sense for a large range of parameters, notably in the low and large inertial number limits [1]. In this communication, we extend the stability analysis of Barker et al. [2] to compressible flows. We show that compressibility regularizes the equations, making the problem well-posed for all parameters, with the condition that sufficient dissipation be associated with volume changes. In addition to the usual Coulomb shear friction coefficient μ , we introduce a bulk friction coefficient μ_b , associated with volume changes and show that the problem is well-posed if $\mu_b > 1 - 7\mu/6$. Moreover, we show that the ill-posed domain defined by Barker et al. [1] transforms into a domain where the flow is unstable but remains well-posed when compressibility is taken into account. These results suggest the importance of taking into account dynamic compressibility for the modelling of dense granular flows and open new perspectives to investigate the emission and propagation of acoustic waves inside these flows. We finally attempt to use this compressible rheology to describe granular flows that exhibit heterogeneous particle density.

[1] Barker, T. et al. (2015). *Journal of Fluid Mechanics*, 779, 794-818.

Wednesday 16:50 Nettuno 2-3

SG14

Granular avalanches down vibrated inclines: an experimental and numerical approach

Naima Gaudel, Sébastien Kiesgen de Richter, Mathieu Jenny, Nicolas Louvet, and Salaheddine Skali-Lami
Université de Lorraine, Vandoeuvre-les-Nancy 54505, France

A major issue of industrial and geophysical interest is the knowledge of granular packing stability. The mechanical properties of granular materials control numerous natural phenomena and are widely encountered in industrial processes (food and pharmaceutical manufactures, construction industry, ...). Most granular flows of industrial interest are free surface flows (vibrated conveyor, silos discharge, ...). These materials are jammed at rest and a finite small perturbation induced by external shear or vibrations can cause the system to flow. In this work, we investigate in detail the free surface flow of monodisperse glass beads subjected to both vibrations and gravity down inclines. The thickness of the layer and the surface velocity in the steady-state are measured for different values of inclination angle, vibration and relative roughness as well as the thickness of the deposits. Our results highlight a competition between gravity and vibrations, two regimes are evidenced: (i) a gravity-driven regime for high-angle where vibrations only modify the thickness of the deposits and does not perturb the velocity and the depth of the flow, for a fixed angle. The apparent scaling law is in agreement with the literature for non-vibrating granular flows; (ii) a vibration-driven regime for low-angle where flows do not occur in the absence of vibrations. We show that the flow can be finely tuned by adding controlled vibrations. In this regime, the flow behavior can be described by an activated process. Numerical simulations based on DEM approach have also been performed. These simulations provide access to information in the depth of the flow in order to understand the vibrations impact at the local scale. All the data are compared with results obtained in the literature for non-vibrating granular flows down inclines and a modified scaling law taking into account vibrations is proposed.

Wednesday 17:10 Nettuno 2-3

SG15

Interparticle friction controls submerged granular flows in simulations

Marko Korhonen, Juha Koivisto, Antti Puisto, and Mikko Alava
Department of Applied Physics, Aalto University, Espoo FI-00076, Finland

Powders, sand and slurries exemplify a class of materials known as granular media, their constituent particles sharing the characteristic length scale of 1-1000 μm . As a result, these systems are athermal and noncolloidal, and instead the mechanical aspects, such as friction and interparticle collisions govern the flow behavior of such materials under external stress of sufficient magnitude. Such granular flows can be witnessed in the industrially relevant silo/hopper geometry, where granular particles exit the hopper via an orifice under the influence of gravity. In these setups, the granular outflow rate is known to follow the Beverloo equation, this rate being independent of the filling height of granular bed inside the hopper. However, the derivation of this equation neglects any particle-fluid interactions present in the system. Recently, experimental work by Wilson et al. involved embedding the particle filled hopper in a viscous interstitial fluid (water). In such a submerged case, the granular outflow is influenced by the particle-fluid interactions and a modified Beverloo equation is required to obtain an agreement. In these experiments, the granular outflow also exhibited a counterintuitive increase (surge) as the hopper was emptied. Theoretical modeling accounting for the appropriate fluid-particle interactions in a CFD-DEM framework [1] was successful in capturing the experimental results. Additionally, we discovered that the interparticle friction governs the surging of the granular phase, which can be understood in the context of an effective shear thickening influence of the friction [2].

[1] Goniva, C. et al. (2012). *Particuology*, 10(5), 582-591. [2] Koivisto, J. et al. (2017). *Soft matter*, 13(41), 7657-7664.

Wednesday 17:30 Nettuno 2-3

SG16

Rheology of dense granular fluids from first principles

Till Kranz and Matthias Sperl
Institute of Material Physics in Space, German Aerospace Center, Cologne, Germany

Granular flows in many industrial processes as well as in landslides and avalanches involve high particle concentration and strong gradients. For modeling purposes a continuum description of these flows is desired. To this end constitutive equations are required that quantitatively predict the non-Newtonian rheology of granular fluids. High shear rates as well as high densities require an approach that goes beyond conventional low density linear response formalisms. We present Granular ITT (Integration Through Transients), a new kinetic theory applicable to the relevant out-of-equilibrium conditions of dense granular fluids that quantitatively captures the complete phenomenology. We discuss the quantitative predictions of our theory in terms of flow curves relating the shear stress to the shear rate and assess its accuracy in comparison to recent experimental results. In essence we find Newtonian behavior at the lowest densities and shear rates, shear thinning when the shear rate exceeds the structural relaxation rate of the fluid, and shear thickening, eventually Bagnold scaling, at the highest shear rates when shear heating dominates. Yield stress behavior is related to the granular glass transition and sets in well below jamming, depending on the particle properties. We find that our theory is well suited to describe the rheology of dense granular fluids over a wide range of shear rates.

Wednesday 17:50 Nettuno 2-3

SG17

Rheology of dense granular materials under steady or dynamic shear

Christopher J. Ness, Rangarajan Radhakrishnan, and Jin Sun
School of Engineering, University of Edinburgh, Edinburgh, United Kingdom

Dry or wet granular materials in natural or industrial processes are generally subjected to complex loadings at various rates and magnitudes, which can be dynamic and induced by, e.g. seismic waves. In order to understand the response of the granular materials to such loadings, we need to have a comprehensive knowledge of the rheology of such materials. We first show a flow regime map obtained through simulations of shear flow of dense granular suspensions using the discrete element method taking particle contact

and hydrodynamic lubrication into account [1]. The flow regimes are mapped in the parametric space of the solid volume fraction, shear rate, fluid viscosity, and particle stiffness. Below a critical volume fraction ϕ_c , the rheology is governed by the Stokes number, which distinguishes between viscous and inertial flow regimes. Above ϕ_c , a quasistatic regime exists for low and moderate shear rates. At very high shear rates, the ϕ dependence is lost, and soft-particle rheology is explored. We then probe the transient stress response to an abrupt reversal of the direction of shear [2] or oscillatory shear. Based on the analysis of the hydrodynamic and particle contact stresses and related contact networks, we demonstrate distinct responses at small and large strains, associated with contact breakage and structural reorientation, respectively. The contact stress is reduced to zero and the hydrodynamic stress dominates at very small strain. They evolve to the steady state at a much larger strain scale of order unity. We further explore the dependence of the dynamic response on strain amplitudes using oscillatory shear, showing viscous and structural response dominates at small and large strain, respectively.

[1] Ness, C., & Sun, J. (2015). *Physical Review E*, 91(1), 012201. [2] Ness, C., & Sun, J. (2016). *Physical Review E*, 93(1), 012604.

Symposium PG

Porous Media, Geo Fluids, Crude Oil & Derivatives

Organizers: Aronne Armanini and Valery Kulichikhin

Wednesday 14:20 Nettuno 4

PG7

Lateral particle migration in random porous media

Rohit V. Maitri¹, Shauvik De¹, Shane Koesen¹, John van der Schaaf¹, Hans Wyss², Frank Peters¹, Johan T. Padding³, and Hans Kuipers¹

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Controlled lateral particle migration in non-Newtonian fluids is very important in many biological, environmental and industrial applications like hydraulic fracturing. The phenomenon of particle transport in non-Newtonian fluids is generally governed by a complex interplay of different effects like shear-thinning or thickening behaviour of the fluid, viscoelasticity and secondary flow. The aim of the current research is to study the migration of particles in a porous microchannel in different fluids. The fluids used here are chosen specifically to investigate isolated as well as combined effects of fluid elasticity and shear-thinning on the particle migration. A periodic array of pillars in a microchannel is used as porous media. The particle distribution in such a microchannel shows a very strong effect of elasticity where particles form a lane by maintaining the maximum possible distance from the pillars. The distribution is wider when fluid is also shear thinning. The particle focussing or lane formation fully disappears when the fluid elasticity is absent. These results are found consistently for a range of porosities. Although highly symmetric and isotropic microchannels, such as mentioned above, give valuable insight in the process, real applications like enhanced oil recovery or hydraulic fracturing involve very anisotropic and heterogeneous transport media. To closely mimic this situation, a microchannel with a random arrangement of pillars is used. The results obtained for this microchannel are compared with the previous results and strong effects of anisotropy is found on the particle migration. Hence, this work gives more insight for designing real-life systems involving particle migration in random porous media.

Wednesday 14:40 Nettuno 4

PG8

Dynamics of elastoviscoplastic flows in porous media

Francesco De Vita¹, Daulet Izbassarov¹, Marco E. Rosti¹, Sarah Hormozi², Outi Tammisola¹, and Luca Brandt¹

¹Mechanics, KTH, Stockholm, Sweden; ²Ohio University, Athens, OH, United States

In this work we present numerical simulations of elastoviscoplastic flow through porous media. We solve the Navier-Stokes equations combined with the elasto-viscoplastic model proposed by Saramito for the stress tensor evolution equation. In this model, the material behaves as a viscoelastic solid when unyielded whereas for stresses higher than the yield stress it behaves as viscoelastic Oldroyd-B fluid. The implementation is based on a finite-difference second order discretization in space and a fractional step time integration. The porous media is made of a symmetric array of cylinders, where we solve the flow in one cell imposing periodic boundary condition. The no-slip boundary condition at the cylinder surface is imposed using an Immersed Boundary Method. We compute the relation between the pressure drop and the flow rate in the porous medium and present empirical closures for different values of the Bingham (ratio of yield stress to viscous stresses) and Reynolds number, quantifying the role of inertia. Although the low Reynolds number, the solution is time dependent. For high Bingham this lead to oscillation in time of the unyielded region and for this reason both instantaneous and average quantities are considered. We shall present distributions of the unyielded region in the material, as well as velocity distribution in the pores. We investigate the strain rate and rotation rate tensors distribution in order to understand the flow topology and compute the effective viscosity for all the cases analysed. Depending on the Bingham number value, we have found both reduction and increase of the apparent viscosity.

Wednesday 15:00 Nettuno 4

PG9

Crossover from linear to non-linear rheological behavior of two-phase flow of Newtonian fluids in porous media

Santanu Sinha¹, Andrew Bender², Matthew Dancsyk², Kayla Keepseagle², Cody Prather², Joshua Bray², Linn W. Thrane², Joseph D. Seymour², Sarah L. Codd², and Alex Hansen³

¹Beijing Computational Science Research Center, Beijing 100193, China; ²Department of Mechanical and Industrial Engineering, Montana State University, Bozeman, MT, United States; ³PoreLab, Department of Physics, Norwegian University of Science and Technology, Trondheim N-7491, Norway

When two immiscible Newtonian fluids flow in a porous medium, the surface tension at the interfaces creates capillary barriers that are needed to pass the narrow pore throats. This distribution of the capillary barriers effectively creates an overall yield threshold reminiscent to a Bingham viscoplastic fluid in the porous medium. In the regime where the capillary forces compete with the viscous forces, the two-phase flow rate do not vary linearly with the total pressure drop anymore and a crossover from linear to non-linear flow regime was observed [1]. For a single capillary tube with a varying diameter, we found that it is a square-root relationship between the flow rate and excess pressure drop [2], and for a network of pores, the relationship is quadratic, which we obtained by mean-field calculations and by pore-network simulations with two dimensional (2D) disordered networks [3]. With our recent numerical studies using three dimensional (3D) reconstructed pore networks, and by experiments with 3D porous medium made with glass beads, we show that the quadratic relationship in the non-linear regime also holds for three dimensions [4]. How the crossover point depends of the fluid saturation, and whether the non-linearity disappears with the decrease in saturation will be addressed further

[1] Tallakstad, K. T. et al. (2009). Physical review letters, 102(7), 074502. [2] Sinha, S. et al. (2013). Physical Review E, 87(2), 025001. [3] Sinha, S., & Hansen, A. (2012). EPL (Europhysics Letters), 99(4), 44004. [4] Sinha, S. et al. (2017). Transport in porous media, 119(1), 77-94.

Wednesday 15:20 Nettuno 4

PG10

Apparent wall slip of viscoelastic fluids with roughened geometries: a porous medium approach

Liana P. Paduano¹, Claudia Carotenuto¹, Thomas Schweizer², Jan Vermant², and Mario Minale¹

¹Industrial and Information Engineering Department, University of Campania Luigi Vanvitelli, Aversa, Italy;

²Material engineering, ETH Zurich, Zurich, Switzerland

Roughened geometries are often used to prevent the apparent wall slip observed with, e.g., multiphase fluids and highly non-Newtonian fluids. The basic idea being that the fluid stands still within the rough layer and the wall slip is prevented. In reality the fluid flows within the rough, porous layer, so at its boundary the velocity is non-zero and an apparent wall slip is introduced. This problem can be treated as the flow of a non-Newtonian fluid through a porous medium and the induced apparent wall slip can be conveniently predicted. This was already done with Newtonian fluids and the predictions agreed very well with the data [1]. In this work we extend this approach to non-Newtonian fluids, by comparing experiments and theoretical calculation. A convenient way to study such problems is with homogenized equations like those of Darcy, or Brinkman. Phenomenological modifications of Darcy's law to account for the fluid viscoelasticity are available in the literature, mainly for shear thinning fluids. Minale [2] developed a generalization of Brinkman's equation for second order fluids and the corresponding boundary condition at the homogeneous fluid/porous medium interface. We experimentally investigate the flow of viscoelastic fluids through porous media by choosing a cross-hatched geometry and a plate with roughness made of parallel pillars as two ideal brush-like porous media. As model fluids we chose two Boger fluids, with different elasticity and a viscoelastic shear thinning fluid. We used an ARES-G2 (TA Instruments) equipped with the cross-hatched geometry and an Anton Paar MCR502 equipped with the plate with pillars. The roughened geometry is mounted on one side of a plate-plate device and we measured both the velocity at the porous medium interface and the first normal stress difference and critically evaluate the experimental results with the model predictions for the second order fluid.

[1] Carotenuto, C. et al. (2015). Journal of Rheology, 59(5), 1131-1149. [2] Minale, M. (2016). Physics of Fluids, 28(2), 023103.

Wednesday 15:40 Nettuno 4

PG11

Controlled formation of hydrate suspensions via frozen emulsions

Michela Geri and Gareth H. McKinley

Mechanical Engineering, MIT, Cambridge, MA, United States

Clathrate hydrates are crystalline compounds that form when a lattice of hydrogen-bonded water molecules is filled by guest molecules sequestered from an adjacent gas or liquid phase. Being able to rapidly produce and transport synthetic hydrates is of great interest given their significant potential as a clean energy source and safe option for gas storage. Understanding hydrate formation is also of great importance for flow assurance as hydrate plugs pose a continuous risk to deepwater production. Conventionally, hydrate suspensions are produced from water-in-oil emulsions seeded with a few ice/hydrates particles to promote hydrate nucleation. This method often yields long nucleation induction times without guaranteeing conversion of all water droplets. Here we describe a new method to rapidly produce hydrate suspensions at ambient pressure, with tunable particle size distribution, by taking advantage of the Rayleigh-Plateau instability to form a monodisperse stream of droplets during the controlled breakup of a water jet. The drops are immediately frozen into ice particles through immersion in a subcooled reservoir and converted into hydrates with a dramatic reduction in the induction time. The resulting frozen emulsion or fromulsion provides a convenient way of transporting the resulting hydrate phase. By measuring the evolution of rheological properties with time, we monitor the process of hydrate formation with different water volume fraction and imposed shear rate. We show that the viscosity evolution is initially dominated by the change in effective volume fraction due to conversion of ice particles into hydrates, independent of water volume fraction and applied shear rate. We complement our rheological study with a thermomechanical analysis and direct visualization of the hydrate formation process. Finally, we show that at later stages particle sintering completely dominates all internal structural rearrangements, leading to the formation of a porous hydrate structure, filled with the residual oil phase.

Symposium PS

Polyelectrolites, Self Assembling Fluids & Gels

Organizers: Dganit Danino, Vincenzo Guida and Laurence Ramos

Wednesday 16:30 Nettuno 4

Keynote PS1

Network topology in soft gels: hardening and softening materialsMehdi Bouzid¹, Minaspi Bantawa², and Emanuela Del Gado³¹University of Paris Sud, Paris, France; ²Institute for Soft Matter Synthesis and Metrology, Georgetown University, Washington, DC, United States; ³Physics, Georgetown University, Washington, DC 20057, United States

The structural complexity of soft gels is at the origin of a versatile mechanical response that allows for large deformations, controlled elastic recovery and toughness in the same material. A limit to exploiting the potential of such materials is the insufficient fundamental understanding of the microstructural origin of the bulk mechanical properties. Here we investigate the role of the network topology in a model gel through 3D numerical simulations. Our study links the topology of the network organization in space to its linear viscoelastic spectrum and to the non-linear rheological response preceding yielding and damage: our analysis elucidates how the network connectivity alone could be used to modify the gel mechanics at large strains, from strain-softening to hardening and even to a brittle response. These findings provide new insight for smart material design and for understanding the non-trivial mechanical response of a potentially wide range of technologically relevant materials.

Wednesday 17:10 Nettuno 4

PS2

Microstructural failure under creep of an agarose gel investigated by space-resolved dynamic light scattering

Angelo Pommella, Laurence Ramos, and Luca Cipelletti

¹Laboratoire Charles Coulomb, University of Montpellier, Montpellier, France

Material failure is common in soft materials that are very susceptible to even modest mechanical loads. Among soft systems, understanding the behavior of biogels under stress is crucial as those gels are very often required to sustain the high stresses typically found in tissue engineering. Under a constant mechanical stress, biogels may show microstructural rearrangements before failure and the detection of any failure precursors would help understanding their failure mechanisms and predicting their failure time. We study the failure of agarose gels, a typical biogel used in food and biomedical applications, thanks to a novel and unique experimental setup that combines rheology and dynamic light scattering. The setup allows a time- and space-resolved investigation of the gel microstructure before failure takes place. We show that, under creep, different dynamic events are present in the gel microstructure which cannot be detected in the macroscopic rheological data. These events show heterogeneity in time, being more frequent approaching gel failure, and in space reflecting the heterogeneity in the gel microstructure. Moreover, these events are observed only in gels showing failure, reinforcing the fact that they may be considered as failure precursors. We believe our findings are general and may apply for many soft materials.

Wednesday 17:30 Nettuno 4

PS3

Wall slip regimes in suspensions of polymer microgels

Marie Le Merrer, Justin Péméja, Baudouin Geraud, and Catherine Barentin

Institut Lumiere Matiere, CNRS, Univ. Lyon 1, Villeurbanne 69622, France

Jammed polymer microgels like polyacrylate-based Carbopol are complex yield stress fluids widely used in applications like cosmetics or oil extraction: solid-like at rest, they become liquids under a sufficient stress. Besides, their flow properties are very dependent upon wall properties, as they can exhibit significant slip, which can drastically affect flow rates under confinement like in porous rocks or in microfluidic channels. We will present wall slip measurements above the yield stress performed on Carbopol in glass microfluidic devices. These are combined with a microscopic characterisation of the polymer structure through fluorescent imaging [1]. In particular, we vary the yield stress, the solvent viscosity and the microstructure size. We show that the wall stress-velocity relation behaves either as a Stokes-like friction, or as a non-linear friction predicted by the elasto-hydrodynamic model of [2]. The transition between both regimes is tuned not only by the confinement of the microgel suspension (as in [3]) but also by the wall stress, which was not reported before.

[1] Géraud, B. et al. (2017). The European Physical Journal E, 40(1), 5. [2] Meeker, S. P. et al. (2004). Physical Review Letters, 92(19), 198302. [3] Divoux, T. et al. (2015). Physical Review E, 92(6), 060301.

Wednesday 17:50 Nettuno 4

PS4

Strand plasticity governs fatigue in colloidal gels

Jasper Van der Gucht, Jan Maarten Van Doorn, Joanne Verweij, and Joris Sprakel

¹Physical Chemistry and Soft Matter, Wageningen University, Wageningen 6708WE, The Netherlands

Repeated loading of a solid leads to microstructural damage that ultimately results in catastrophic material failure. While posing a major threat to the stability of virtually all materials, the microscopic origins of fatigue, especially for soft solids, remain elusive. Here we explore fatigue in colloidal gels as prototypical inhomogeneous soft solids by combining experiments and computer simulations. Our results reveal how mechanical loading leads to irreversible strand stretching, which builds slack into the network that softens the solid at small strains and causes strain hardening at larger deformations. We thus find that microscopic plasticity governs fatigue at much larger scales. This gives rise to a new picture of fatigue in soft thermal solids and calls for new theoretical descriptions of soft gel mechanics in which local plasticity is taken into account.

Symposium BE

Blends, Emulsions, Foams & Interfacial Rheology

Organizers: Ernesto Di Maio, Peter Van Puyvelde and Jan Vermant

Wednesday 14:20 Nettuno 5-6

BE8

Dilational surface rheology of pulmonary surfactants in broad range of surface pressuresAleksei Bykov and Boris Noskov*Saint-Petersburg State University, Saint-Petersburg, Russia*

Almost all the investigations of dynamic surface properties focused on small deformations when a response of the system is proportional to the deformation (linear behavior). In this work a new approach to the analysis of nonlinear surface dilational rheological properties was developed with the aim to enlarge the accessible range of surface pressures for measurements of surface elasticity of pulmonary surfactants. It has been proposed recently that the method of stress decomposition can be used for the determination of the dynamic surface elasticity from the non-linear response for compressed and expanded state of surface layer [1]. In this work, to describe the non-linear behavior a modified stress decomposition method was proposed. It takes into account the contribution from small deformation into the non-linear response and leads to much better agreement between results for small and large deformations. The application of the modified stress decomposition method for the investigation of spread monolayers of dipalmitoyl phosphatidylcholine (DPPC) allowed us to determine the dilational surface elasticity in dynamic state at extremely low values of surface tension (up to 1 mN/m). We also investigated mixed monolayers of DPPC with cholesterol and di-myristoyl phosphatidylethanolamine at the same conditions. It was shown that the addition of other components led to an increase of the dynamic surface elasticity and minimal values of the surface tension, which can be achieved under compression of the surface. Finally, dilational surface elasticity for solutions of pulmonary surfactants (extracted from animals) was measured based on our approach. It was shown that dilational surface elasticity proved to be high up to the collapse. Acknowledgement: The work was financially supported by the Russian Science Foundation (project No. 17-73-10171).

[1] Bykov, A. G. et al. (2015). *Advances in colloid and interface science*, 222, 110-118.

Wednesday 14:40 Nettuno 5-6

BE9

Topological rearrangements and surface rheology : a multi-scale approach on dairy proteins foamsAlexia Audebert¹, Stéphane Pezenne¹, Sylvie Beauvils², Valérie Lechevalier¹, Cécile Le Floch-Fouéré¹, Arnaud Saint-Jalmes², and Simon Cox³¹INRA, STLO, UMR1253, Rennes, France; ²CNRS, Institute of Physics Rennes, UMR6251, Rennes, France;³Aberystwyth University, Institute of Mathematics, Physics and Computer Science, Aberystwyth, United Kingdom

The main destabilisation processes in aqueous foams are liquid drainage, coalescence and disproportionation. Due to their amphiphilic nature, proteins can reduce surface tension Γ , increase liquid phase viscosity and form a visco-elastic interfacial film surrounding the gas bubbles. A correlation is believed to exist between surface rheology of the protein interfacial film and foam stability. Indeed, surface rheology on protein films helps the understanding of foam stability. Two kinds of surface deformation may be applied on a single planar protein film, shearing and expansion/compression (or dilatation). The dilatational elasticity modulus must be larger than 2Γ to prevent disproportionation. A higher surface shear viscosity is correlated with a better stability against drainage. More generally, higher surface shearing modulus improved stability. However, full understanding still is a challenge because of foam complexity. Foams have confined interstices and spontaneous dynamic rearrangements happen, which cannot be reproduced using only single planar interfaces. Thus, the goal of this work is to bring a multi-scale approach by combining dynamical T1 topological rearrangements of protein films to interfacial rheology measurements. T1 rearrangements occur spontaneously during a foam lifetime or as it flows inside a pipe for example. For small-molecular-weight surfactants, their kinetics have been shown to be an important parameter for the foam stability. In the present work, we aimed at studying the relationship between the rheology of protein interfacial films and the kinetics of T1 rearrangements in protein foams. Two dairy commercial products were studied, sodium caseinate and whey protein isolate (WPI). They differ by their molecular structure and surface rheological properties. Purified β -Lactoglobulin, the main protein in WPI, has also been evaluated. Links between T1, surface rheology and foaming properties will be discussed.

Wednesday 15:00 Nettuno 5-6

BE10

Shear and dilatational viscoelasticity of saponin adsorption layersSlavka Tcholakova, Konstantin Golemanov, Sonia Tsibranska, and Nikolai Denkov¹Department of Chemical and Pharmaceutical Engineering, Sofia University, Sofia 1164, Bulgaria

Saponins are natural surfactants with non-trivial surface and aggregation properties which find numerous important applications in several areas (food, pharma, cosmetic and others). We studied systematically [1-3] the surface properties of ten saponin extracts, having different molecular structure with respect to the type of their hydrophobic fragment (triterpenoid or steroid) and the number of sugar hydrophilic chains (1 to 3). We found that some of the triterpenoid saponins (Escin, Tea Saponin and Ginsenosides) have relatively small area per molecule (0.5 to 0.7 nm²) of their molecules in adsorption layers and these molecules are orientated perpendicularly to the interface. The same saponins are characterized with very high surface elasticity of their adsorption layers (up to 2000 mN/m) for both air-water and oil-water interfaces. The comparison of the experimentally measured surface elasticities with theoretically estimated ones shows that these saponins have molecular interaction parameter in the adsorption layers which is above the threshold value for two-dimensional phase transition. These highly elastic layers are in surface condensed state, due to strong attraction between the adsorbed molecules. Molecular computer modelling showed [4] that the adsorbed saponin molecules attract strongly each other via several types of intermolecular forces which all contribute to the remarkable rheological properties of the adsorption layers. In contrast, the adsorption layers from steroids saponins are characterized with weak intermolecular attraction

within the layer and, therefore, have zero shear elasticity and viscosity and low dilatational elasticity and viscosity, comparable in magnitude to those reported in the literature for protein adsorption layers.

[1] Golemanov, K. et al. (2013). *Soft Matter*, 9(24), 5738-5752. [2] Golemanov, K. et al. (2014). *Soft Matter*, 10(36), 7034-7044. [3] Pagureva, N. et al. (2016). *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 491, 18-28. [4] Tsibranska, S. et al. (2017). *Langmuir*, 33(33), 8330-8341.

Wednesday 15:20 Nettuno 5-6

BE11

Effect of oil hydrophobicity on adsorption and rheology of β -lactoglobulin at oil-water interfaces

Jotam Bergfreund, Pascal Bertsch, and Peter Fischer

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The rheological behavior of protein layers at water-oil interfaces is critical to understand and predict emulsion formation and stability. Effects of ionic strength, pH, temperature and several pre-treatments are well-known. However, the oil phase has been regarded as exchangeable and its role in the protein adsorption mechanisms has been widely ignored. By measuring adsorption kinetic, dilatational and interfacial shear moduli, the influence of systematically selected oil interfaces of high purity on the formation and properties of β -lactoglobulin layers was evaluated. A delayed protein solution injection enabled the measurement of the viscoelastic response of protein layer formation at an uncontaminated water-oil interface. It was found that depending on molecular size, flexibility, hydrophobicity, and polarizability of the oils, globular proteins adsorb distinctively. Stronger interactions of polar oils with the hydrophilic exterior of the native β -lactoglobulin lead to a decelerated protein unfolding. This results in lower surface pressures and slower formation of viscoelastic networks. In addition, polar oils interact stronger with the protein network by hydrophilic bonding and thereby act as softening agents. The found effects of hydrophobic subphases on the adsorbed protein layers provide knowledge which promotes higher reproducibility in rheological studies and precise tailoring of interfacial films for an enhanced formation and stability of emulsions.

Wednesday 15:40 Nettuno 5-6

BE12

Towards rheology of lipid bilayers

Jan Vermant, Peter Beltramo, and Laura Scheidegger

Material engineering, ETH Zurich, Zurich, Switzerland

Lipid bilayers constitute an important building block of cells. Rheological properties play an important role in transport phenomena both in the plane (e.g. diffusion of membrane proteins) as across the membrane (reactions to changes in tension). In this work we present our progress made in using a LAMB device [1] for the measurements of the properties of large area lipid bilayers using a modified thin film balance. We measure the electrostrictive compressibility, the response to oscillatory changes in membrane tension and the in plane diffusion. We will discuss how a holistic view on membrane bi layer rheology can be pursued

[1] Beltramo, P. J. et al. (2016). *Soft Matter*, 12(19), 4324-4331.

Wednesday 16:30 Nettuno 5-6

BE13

Viscous, elastic, and viscoelastic interfaces - the effect of polymer chain flexibility

Daniel Ashkenazi and Moshe Gottlieb

Chemical Engineering, Ben Gurion University, Beer Sheva 8410501, Israel

The relationship between the phase behavior of polymer monolayers as studied by the classical rectangular Langmuir-Pockels trough and the rheological properties of the interface and the importance of the detailed test geometry was recently described and analyzed in detail [1]. In this contribution we study the behavior of monolayers formed by two very distinctly different polymers: poly(ter butyl methacrylate) - a glassy polymer, and polydimethylsiloxane - a highly flexible polymer. The effect of deformation rates (De number) and relaxation behavior as exhibited by the polymer in the surface pressure-area experiments is contrasted with rheological data and interfacial organization. Highly different behavior is observed when comparing the two polymers attributed to the chain flexibility.

[1] Pepicelli, M. et al. (2017). *Soft matter*, 13(35), 5977-5990.

Wednesday 16:50 Nettuno 5-6

BE14

The bicone interfacial shear rheometer revisited: flow field based data processing for the oscillating conical bob

Javier Tajuelo¹, Juan M. Pastor², and Miguel Ángel Rubio¹

¹Departamento Física Fundamental, Universidad de Educación a Distancia, Madrid, Madrid 28040, Spain;

²Ingeniería Agroforestal, Universidad Politécnica de Madrid, Madrid, Madrid 28040, Spain

Conventional rotational rheometers are usually available in most rheology laboratories. These systems can be easily transformed into interfacial shear rheometers (ISR) by means of proper accessories that allow one to shear fluid-fluid interfaces in a controlled manner. Actually, most rotational rheometer manufacturers sell special fixtures for interfacial shear rheometry measurements, so that bicone, Du Nouy ring, or double-wall ring (DWR) fixtures are rather popular. However, fully exploiting the capabilities of these systems, by recovering accurate values of the dynamic moduli from the torque and angular displacement raw data, is far from trivial. A strategy that has been successful in dynamic measurements, both in the DWR [1] and the magnetic rod ISR [2-6], is to properly account for the interface and subphase drags by numerically finding the corresponding flow fields and, thereafter, using an iterative scheme to recover the proper values of the complex Boussinesq number and the dynamic surface moduli. We will illustrate how to use such a scheme in interfacial dynamic measurements with a homemade bicone fixture. We show that an adequate numerical scheme can account for different configurations (either bob or cup as moving part performing oscillatory or constant velocity

rotation) just by changing the boundary conditions. We will illustrate the performance of our scheme on several interfacial experimental systems.

[1] Vandebril, S. et al. (2010). *Rheologica Acta*, 49(2), 131-144. [2] Brooks, C. F. et al. (1999). *Langmuir*, 15(7), 2450-2459. [3] Reynaert, S. et al. (2008). *Journal of Rheology*, 52(1), 261-285. [4] Verwijlen, T. et al. (2011). *Langmuir*, 27(15), 9345-9358. [5] Tajuelo, J. et al. (2015). *Langmuir*, 31(4), 1410-1420. [6] Tajuelo, J. et al. (2016). *Journal of Rheology*, 60(6), 1095-1113.

Wednesday 17:10 Nettuno 5-6

BE15

Linear shear rheology of aging β -casein films adsorbing at the air/water interface

Fernando Martínez-Pedrero¹, Javier Tajuelo², Pablo Sánchez-Puga², Francisco Ortega¹, Miguel Ángel Rubio², and Ramón G. Rubio¹

¹*Química-Física I, Universidad Complutense de Madrid, Madrid, Madrid 28040, Spain;* ²*Departamento de Física Fundamental, Universidad Nacional de Educación a Distancia, Madrid, Madrid 28040, Spain*

In this work, the viscoelasticity of β -casein films has been measured using different macro- and microrheological techniques, done with multiple probe sizes. The experiments allowed monitoring of the protein adsorption and annealing, and demonstrated both, that β -casein adsorption creates a soft glassy gel at the interface that experiences an aging process, and the consistency of the surface rheological measurements over a broad range of viscosities.

Wednesday 17:30 Nettuno 5-6

BE16

Understanding the foamability and mechanical properties of foamed polypropylene blends by shear and extensional rheology

Ester Laguna-Gutierrez¹, Rob Van Hooghten², Miguel Angel Rodriguez-Perez¹, and Paula Moldenaers²

¹*Condensed Matter Physics Department, CellMat Laboratory, University of Valladolid, Valladolid 47011, Spain;*

²*Department of Chemical Engineering, Katholieke Universiteit Leuven, Leuven 3001, Belgium*

In this work the influence of the rheological behaviour of miscible blends of a linear and a high melt strength, branched, polypropylene (HMS PP), on the cellular structure and mechanical properties of cellular materials fabricated with these polypropylenes (PPs) has been investigated. The rheological properties of the polypropylene melts were investigated in steady as well as oscillatory shear flow and in uniaxial elongation in order to determine the strain hardening coefficient. While the PP blends display very similar behaviours in shear, there are substantial differences in the elongational behaviour. Cellular materials with a fixed relative density of 0.2 have been fabricated by Improved Compression Moulding (ICM), a technique that allows controlling the foam density by mechanical means. The open cell content has been quantified and a detailed characterization of the cellular structure has been performed. In addition, mechanical properties in compression have been measured. While the linear PP does not exhibit strain hardening, the blends of the linear and the HMS PP show pronounced strain hardening, increasing with the concentration of HMS PP. A relation has been observed between the strain hardening coefficient and the open cell content: more strain hardening leads to a lower open cell content. Related with cellular structure, in general, the cell size and the width of the cell size distribution, increase with the amount of linear PP in the blends. These results indicate that the cell walls are less stable when large amounts of linear PP are used. Also mechanical properties are conditioned by the extensional rheological behaviour of PP blends. Cellular materials with the best mechanical properties are those that have been fabricated using large amounts of HMS PP. The results demonstrate the importance of the extensional rheological behaviour of the polymers for a better understanding and steering of the cellular structure and properties of the cellular materials.

Wednesday 17:50 Nettuno 5-6

BE17

The role of elasticity in pore wall breaking

Daniele Tammaro, Rossana Pasquino, Massimiliano M. Villone, Gaetano D'Avino, Vincenzo Ferraro, Ernesto Di Maio, Antonio Langella, Nino Grizzuti, and Pier Luca Maffettone

Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

When a Newtonian bubble ruptures, the film retraction dynamics is controlled by the interplay of surface, inertial and viscous forces. In case a viscoelastic liquid is considered, the scenario is enriched by the appearance of a new significant contribution, namely, the elastic force. In this paper, we investigate experimentally the retraction of viscoelastic bubbles inflated at different blowing rates, showing that the amount of elastic energy stored by the liquid film enclosing the bubble depends on the inflation history and, in turn, affects the velocity of film retraction when the bubble is punctured. Several viscoelastic liquids are considered. We also perform Direct Numerical Simulations to support the experimental findings. Finally, we develop a simple heuristic model able to interpret the physical mechanism underlying the process.

Thursday Morning

Symposium PL

Plenary Lectures

Thursday 8:30 Sirene

PL2

Microscopic design of soft colloidal materials

Michel Cloitre

Laboratoire Matière Molle et Chimie, ESPCI ParisTech, Paris 75005, France

At high concentration, dispersions of deformable particles such as emulsions, microgels, micelles and star polymers jam into glassy materials that behave as weak elastic solids at rest but yield and flow at high stresses. These materials are basic components of viscoplastic formulations used as high-performance coatings, solid inks, ceramic pastes, textured food, or personal care products. The packed amorphous microstructure of soft particle glasses lies at the heart of their rheological behavior. Individual particles are trapped in cages and can only move past one another appreciably if the local stress exceeds the strength of the contact interactions. Interestingly, chemistry offers a panel of strategies to tune the internal architecture of particles, the local elasticity, and the contact interactions, which generally involve elastic repulsion and attractions of different origins. We will review recent advances that bridge the gap between particle scale properties and macroscopic rheology, thereby opening new routes towards the rational design of soft colloidal materials.

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Thursday 9:30 Sirene

CS18

Rheology of jammed suspensions of anisotropic particles

Hiya Goswami and Jyoti R. Seth

Chemical Engineering, Indian Institute of Technology Bombay, Mumbai, Maharashtra 400076, India

Filler particles are often used to tailor the rheology of products from consumer goods, food, pharmaceutical and other industries. Examples include creams, ointments, margarine, etc.. Typically, a network of particles is formed in situ by, first dissolving or melting structuring agents such as fatty acids, and then cooling the mixture. Highly anisotropic particles crystallise and grow to yield a jammed suspension which becomes solid-like even at very low volume fractions. The solid-like rheology of these products at rest is crucial for long-term stability. Moreover, such suspensions are examples of random, self-generated networks with interesting rheological characteristics. This talk will focus on the dynamics of deformation and recovery of model suspensions of stearic acid in mineral oil. Results from creep experiments at stresses below and above the yield stress will be presented. While the initial strain response is as expected, there is seen a logarithmic increase in strain at long times, even at stresses below the yield value. Furthermore, an anomalous strain response is observed for applied stress much smaller than the yield value. Interestingly, when the applied stress is removed, strain recovers in a manner similar to colloidal glasses. The influence of crystal shape and size on creep and recovery has also been investigated. Finally, experimental findings from particle tracking velocimetry reveal the internal dynamics of these suspensions during deformation.

Thursday 9:50 Sirene

CS19

A rheological constitutive model for semiconcentrated rod suspensions in Bingham fluids

Julien Férec¹, Erwan Bertevas², Boo Cheong Khoo², Gilles Ausias¹, and Nhan Phan-Thien²

¹*Université Bretagne Sud, Lorient, France;* ²*National University of Singapore, Singapore, Singapore*

A cell model is used to develop a constitutive equation for a suspension of rigid rods in a Bingham fluid. This approach, which is valid for particle volume fractions ranging up to the semiconcentrated regime, allows expressing the shear stress on the particle surface and introduces no tuning parameters. Hence, for Bingham numbers less than unity, a straightforward relationship for the suspension yield stress is obtained in terms of the moments for the orientation distribution probability, also known as the orientation tensors. It is found that the presence of rods leads to an increase in the yield stress values and more significantly, it is related to the average particle orientation. The effect of rod orientation on the yield stress surface is investigated by considering the model response under a shear/elongational flow. It appears that the shear yield stress for randomly oriented rods is lower than the one for the case where all particles are aligned with the flow direction. The model predictions are tested against shear stress experiments for kaolin pastes filled with steel fibers having two different aspect ratios. Good agreement is observed since the model predictions give qualitative and quantitative bounds for yield stresses of both suspensions. Particle dynamics in a Bingham fluid was also determined: The Jeffery solution expressed for slender bodies, in which a diffusivity perturbation term proportional to the yield stress of the unfilled matrix is introduced, is found to be suitable. Hence, a similar moment-tensor-based evolution equation for the microstructure, which is useful at the macroscopic level, is obtained from the Giesekus stress tensor and from the kinetic-theory. It is also found that

the rod microstructure will evolve with the flow if the applied stress exceeds the threshold stress and will otherwise remain unchanged.

Thursday 10:10 Sirene

CS20

Modeling, simulation and rheology of particulate systems interacting with a viscoelastic matrix

Adolfo Vázquez-Quesada¹, Roger I. Tanner², and Marco Ellero¹

¹Zienkiewicz Centre for Computational Engineering, Swansea University, Swansea, United Kingdom; ²School of Amme, University of Sydney, Sydney, New South Wales 2006, Australia

In this talk, an extension of the Smoothed Particle Hydrodynamics (SPH) suspension model -previously developed for Newtonian suspending media [1]- to viscoelastic matrices [2] is presented. For the solvent medium, the coarse-grained SPH viscoelastic formulation proposed initially in [3] is adopted. The property of this particular set of discrete equations is that they are entirely derived within the General Equation for Non-Equilibrium Reversible-Irreversible Coupling (GENERIC) framework and therefore enjoy automatically thermodynamic consistency. The viscoelastic model is derived through a physical specification of a conformation-tensor-dependent entropy function for the fluid particles. It is straightforward to extend the present particulate model to Brownian conditions, i.e. leading to a thermodynamic consistent viscoelastic colloidal suspension model [4]. We validate the suspension model by studying the dynamics of single and mutually interacting non-Brownian (i.e. non-colloidal) rigid spheres under shear flow and in the presence of confinement. Simulations agree well with available numerical and experimental data [2]. Finally, some results on the rheology of the corresponding viscoelastic suspension under dilute and moderately concentrated conditions will be presented and discussed in relation to existing rheological data [5, 6].

[1] Vázquez-Quesada, A. et al. (2017). *Journal of Non-Newtonian Fluid Mechanics*, 248, 1-7. [2] Vázquez-Quesada, A., & Ellero, M. (2017). *Physics of Fluids*, 29(12), 121609. [3] Vázquez-Quesada, A. et al. (2009). *Physical Review E*, 79(5), 056707. [4] Vázquez-Quesada, A. et al. (2012). *Microfluidics and nanofluidics*, 13(2), 249-260. [5] Zarraga, I. E. et al. (2001). *Journal of Rheology*, 45(5), 1065-1084. [6] Dai, S. C. et al. (2014). *Journal of Rheology*, 58(1), 183-198.

Thursday 10:30 Sirene

CS21

Dimorphic magnetorheological suspension based on sepiolite needles

Jéssica Marins, Pavel Kuzhir, Tomas Plachy, and Georges Bossis

¹Institute of Physics of Nice, University of Nice-Sophia Antipolis, Nice 06108, France

Magnetorheological (MR) suspensions belong to a class of smart materials which exhibit sharp and reversible phase transition from a viscous fluid-state to a solid-like state under an applied external magnetic field. Sepiolite (SEP) is a natural microcrystalline-hydrated magnesium silicate, exhibiting a peculiar micro fibrous morphology. This needle-like morphology with large aspect ratio makes this natural clay mineral a very promising additive to magneto- and electrorheological fluids. The aim of the present work is to show synergistic effect of SEP to increase MR effect and reduce sedimentation. To this purpose, we used high concentration of SEP 1-5 vol.% with 5, 10 and 20 vol.% of carbonyl iron (CI) particles in silicone oil. To understand the interaction among SEP, CI particles and silicone oil, the suspension was reticulated to be analysed by SEM and by EDX showing that SEP fibers were well dispersed in the suspension without being adsorbed onto CI particles. The off-state viscosity of CI suspension increases as a function of volume fraction of SEP, at the same time sedimentation velocity considerably decreases with SEP concentration. The suspensions of CI mixed with SEP fibers generally showed a better MR effect than the suspensions of CI without SEP addition. The dynamic yield stress was shown to be 60% larger for the suspension containing 5% SEP as compared to that without SEP at the CI volume fraction of 10% and at an applied magnetic field of 31 kA/m.

Thursday 11:20 Sirene

CS22

Structure and rheology of cellulose nanofibrils suspensions and hydrogels: effect of volume fraction and ionic strength

Fatima Fneich, Julien Ville, Bastien Séantier, and Thierry Aubry

¹IRDL - FRE CNRS 3744, Université de Bretagne Occidentale, Brest, Bretagne 29 200, France

In recent years, cellulose nanofibrils (CNF) were used as biosourced nanofibers in the formulation of many promising materials. The present study focuses on the structural and rheological properties of TEMPO-oxidized CNF suspensions and hydrogels, used as precursors in the elaboration of bio-based aerogels for thermal insulation applications. Using an electric conductivity titration method, the CNF carboxylate content was shown to be 1.12 mmol/g, whereas, from XRD measurements, the CNF degree of crystallinity was shown to be about 75%. Analysis of AFM observations has shown that the CNF aspect ratio was about 120 and that their persistence length was of the same order of magnitude as their length. Viscometric measurements were performed at very low CNF concentrations. Intrinsic viscosity and Huggins coefficient of CNF suspensions in deionized water were shown to be in relatively good agreement with Berry and Russel model for rigid rod-like particles. Moreover, intrinsic viscosity results at various ionic strengths highlighted the prominent role played by primary electroviscous effects at very low ionic strengths, and suggested the existence of aggregation phenomena once the electrostatic repulsive interactions are screened, even in the dilute regime. Oscillatory and steady shear measurements on semi-dilute CNF suspensions revealed the formation of a three-dimensional hydrogel network above a volume fraction of about 0.2%. Above this percolation threshold, the linear viscoelasticity results have shown the existence of two different regimes, attributed to two different hydrogel structures, separated by a volume fraction of about 0.4%. Quite interestingly, this transition fraction also marks a change in the structure and properties of aerogels elaborated from these studied hydrogels. The results of the present work will be used to improve the design and elaboration of innovative environmentally friendly bioaerogels.

Thursday 11:40 Sirene

CS23

Shear-induced resuspension of spherical particles in a Couette device: measurement of the steady concentration profiles

Enzo D'Ambrosio, Elisabeth Lemaire, and Frédéric Blanc

¹*InPhyNi UMR 7010, UCA, Nice, Alpes Maritimes 06108, France*

The shear-induced resuspension of solid particles involves an upward flux of solid particles which balances the gravity flux due to density mismatch between the particles and the suspending liquid. More precisely, the parameter that controls resuspension is the Shields number that is the ratio of the hydrodynamic force to the weight of the particles exerted on the bottom particle layer. The particle resuspension that arises when a shear is applied is a specific situation of shear-induced migration and can be interpreted by several theoretical models. The first model has been developed by Acrivos, Morris and Fan in 1993 and links the resuspension to shear-induced particle diffusion. A second model that can be used is the Suspension Balance Model (SBM), developed by Morris and Boulay in 1999. In this model, the particle migration flux is proportional to the divergence of the particle stress tensor whose components depend on both the shear rate and the particle fraction. The point of our experiment is to measure the concentration profiles during resuspension in order to check the validity of the models cited above. A suspension of dense particles is sheared in a Couette flow which is lighted by a vertical laser sheet. The suspension is made transparent by an accurate matching of the refractive index of the solid and liquid phases. With an appropriate image processing, the experimental profiles of concentration are determined for various Shields numbers and they are compared to the theoretical predictions provided by SBM and diffusion models.

Thursday 12:00 Sirene

CS24

Flocculation of non-Brownian suspensions

Alexander Zinchenko

Chemical and Biological Engineering, University of Colorado, Boulder, CO 80309, United States

Microstructural evolution and temporal dynamics of the sedimentation rate $U(t)$ are studied for a monodisperse suspension of non-Brownian spherical particles subject to van der Waals attraction and electrostatic repulsion in the realistic range of colloidal parameters (Hamaker constant, surface potential, double layer thickness). A novel economical high-order multipole algorithm is used to fully resolve hydrodynamical interactions in the dynamical simulations with up to 500 spheres in a periodic box and $\sim 200\,000$ time steps, combined with geometry perturbation technique (Zinchenko A.Z. Phil. Trans. R. Soc. Lond. A (1998), vol. 356, 2953-2998) to incorporate lubrication and extend the solution to arbitrarily small particle separations. The character of flocculation during sedimentation is mostly affected by the maximum magnitude of the attractive force relative to the effective gravity force on a particle. Accordingly, there are cases of almost irreversible flocculation where particles form strong but flexible bonds in the secondary minimum, and the cases of weaker attraction with reversible flocculation. Ensemble averaging over many initial configurations of a well-mixed suspension of unaggregated spheres is used to predict $U(t)$ for particle volume fractions between 0.1 and 0.25 in a wide time range. The results are fully convergent and system-size independent. When $U(t)$ is scaled with its initial value for a well-mixed system, kinetics of the sedimentation rate is found to be only weakly sensitive to the volume fraction. It follows from the simulations that for suspended particles of ~ 10 -15 micron size, flocculation is ubiquitous and has a large effect. Namely, the sedimentation rate is expected to grow at least several fold before it can (possibly) reach a steady state after a long time. The regime of steady sedimentation is indeed achieved in the simulations with weaker attractions but it still shows significantly faster sedimentation rates than for a well-mixed suspension of unaggregated spheres.

Thursday 12:20 Sirene

CS25

Advances in thixotropy modeling of suspensions applied to fumed silica, carbon black and blood.

Norman J. Wagner¹ and Antony N. Beris²

¹*Chemical and Biomolecular Engineering, University of Delaware, Newark, DE 19716, United States;* ²*University of Delaware, Newark, DE 19716, United States*

Recent advances in modeling thixotropy are reviewed whereby a particle-level population balance model is extended to be applicable to thixotropic colloidal suspensions with yield stress and coarse grained. A reduced model is derived and validated against experimental data on a variety of model systems available in the literature. Modifications are made to account for dynamic arrest at the onset of the yield stress, in addition to enforcing a minimum particle size below which breakage is not feasible. The resulting constitutive model also incorporates a structural based relaxation time, unlike existing phenomenological models that use the inverse of the material shear rate as the relaxation time. The model provides a reasonable representation of experimental data for a model thixotropic suspension in the literature, capturing the important thixotropic timescales. Extensions to multicomponent suspensions based on recently published theoretical work are made and evaluated. When compared to prevalent structure kinetics models, the coarse-grained population balance equation is shown to be distinct, emphasizing the novelty of utilizing population balances as a basis for thixotropic suspension modeling. Applications to new data sets probing the thixotropy of fumed silica, carbon black and human blood are discussed, along with new developments working towards a fully thermodynamically consistent framework for thixotropy modeling.

Thursday 12:40 Sirene

CS26

TEMPO-oxidized cellulose nanofibrils: probing the mechanisms of gelation via Small-Angle X-Ray Scattering and RheologyJulien Schmitt¹, Vincenzo Calabrese¹, Marcelo A. da Silva¹, Saskia Lindhoud¹, Viveka Alfredsson², Janet L. Scott¹, and Karen J. Edler¹¹*Department of Chemistry, University of Bath, Bath BA2 7AY, United Kingdom;* ²*Physical Chemistry, Lund University, Lund SE-22100, Sweden*

Cellulose, as the most abundant natural polymer, is extensively studied in the formulation of new biodegradable materials, as it is biocompatible and environmentally friendly [1]. It can be isolated from various sources (wood pulp, bacteria, tunicates and others) yielding variously shaped particles. Chemical modification allows dispersion of individualised fibrils. Specifically, oxidized cellulose nanofibrils (OCNF), obtained by TEMPO-mediated oxidation of plant or bacterial cellulose [2], present a high negative surface charge making them easy to disperse in water [3]. Rheology studies demonstrate that OCNF suspensions have shear-thinning properties and form gels upon concentration (e.g. above 1.5 wt%), or in the presence of additives, such as salts (e.g. NaCl) [3]. TEM and SAXS experiments have been performed to describe the shape of the fibrils, found to be rigid cylinders with typically 5 nm cross sections and up to several hundred nm in length. SAXS measurements of suspensions and gels provide a basis for studying the fibril-fibril interactions between the OCNF upon concentration or in presence of additives and relate interactions to the rheological behaviour. The effect of concentration can be modelled by the Random Phase Approximation, describing repulsive interactions between fibrils [4], whereas addition of NaCl results in the appearance of an attractive interaction between OCNF. By comparing both SAXS and rheology, some light is shed on the gelation mechanisms operating in aqueous OCNF dispersions.

[1] Klemm, D. et al. (2005). *Angewandte Chemie International Edition*, 44(22), 3358-3393. [2] Isogai, A. et al. (2011). *Nanoscale*, 3(1), 71-85 [3] Crawford, R. J. et al. (2012). *Green chemistry*, 14(2), 300-303. [4] Shimada, T. et al. (1988). *The Journal of Chemical Physics*, 88(4), 2815-2821.

Symposium NF**Non Newtonian Fluid Mechanics & Flow Instabilities**

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Thursday 9:30 Ulisse

NF18

Buckling of viscoplastic fluid filaments under compression stressesAnselmo S. Pereira, Romain Castellani, Mehdi Khalloufi, Elie Hachem, and Rudy Valette¹*MINES ParisTech -- CEMEF, PSL Research University, Sophia Antipolis 06904, France*

Fluid buckling instabilities represent a major source of irregularities for several industrial and natural processes such as container filling, glass plate fabrication and folding of geological structures. Despite some recent and significant works regarding such instabilities in Newtonian fluids, the buckling of non-Newtonian materials remains scarcely explored in the literature. In the present work, we analyse through scaling laws and direct numerical simulations the buckling of filaments of a viscoplastic Bingham fluid compressed at constant velocity by two parallel plates. Under low gravity conditions (the Laplace pressure exceeds the hydrostatic pressure), three regimes are observed for slender filaments: a first one driven by the capillary force and during which there is no deflection and a folding regime that is dominated by the compressive viscous force and for which the inertia is negligible, as found by Le Merrer, Quéré and Clanet [1]; and a twist/coil regime appearing at larger Reynolds number. Introducing a yield stress induces localization that restricts the buckled flow dimensions. Our main results are summarized in a four-dimensional phase diagram whose axes are a slenderness parameter, capillary number, Reynolds number and Bingham number.

[1] Le Merrer, M et al. (2012). *Physical review letters*, 109(6), 064502.

Thursday 9:50 Ulisse

NF19

Equations of motion from the nonequilibrium statistical mechanical theory for material in deformationKwang Soo Cho¹ and Peter J. Daivis²¹*Kyungpook National University, Daegu, Republic of Korea;* ²*Physics, RMIT University, Melbourne, Victoria 3000, Australia*

We consider a system of deforming material interacting with its environment and introduce a nonequilibrium statistical mechanical theory based on the formalism of McLennan [1]. The result is a set of equations of motion, which are a modification of the SLLOD equations of nonequilibrium molecular dynamics simulation [2]. These equations of motion reflect the influence of the environment and satisfy the mathematical form of the balance equations of mass, momentum and energy in continuum mechanics. We derived the equation of motion from the evolution equation of the probability distribution of the system interacting with the environment. The balance equations lead to molecular expressions for the stress and heat flux which are nearly identical to those of Irving and Kirkwood [3]. We expect that our formalism will be helpful to develop constitutive equations of complex fluids because the theory involves macroscopic kinematics in an exact manner.

[1] McLennan, J. A. (1963). *Adv. Chem. Phys.* [2] Evans, D. J., & Morriss, G. P. (1984). *Physical Review A*, 30(3), 1528. [3] Irving, J. H., & Kirkwood, J. G. (1950). *The Journal of chemical physics*, 18(6), 817-829.

Thursday 10:10 Ulisse

NF20

Direct observation of orientation distributions of actin filaments in a solution undergoing shear banding

Katsuhiko Sato¹, Itsuki Kunita², Yoshinori Takikawa³, Daisuke Takeuchi⁴, Yoshimi Tanaka⁵, Toshiyuki Nakagaki¹, and Hiroshi Orihara⁴

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Shear banding is frequently observed in complex fluids. However, the configuration of macromolecules in solutions undergoing shear banding has not yet been directly observed. In this study, by using the fact that F-actin solutions exhibit shear banding and actin filaments are visualized by fluorescent labels, we directly observed the intrinsic states of an actin solution undergoing shear banding. By combining the 3D imaging of labeled actin filaments and particle image velocimetry (PIV), we obtained orientation distributions of actin filaments in both high and low shear rate regions, whose quantitative differences are indicated. In addition, by using the orientation distributions and applying stress expression for rod-like polymers, we estimated stress tensors in both high and low shear rate regions. This evaluation indicates that different orientation distributions of filamentous macromolecules can exhibit a common shear stress.

Thursday 10:30 Ulisse

NF21

Transient shear banding in the nematic dumbbell model of liquid crystalline polymers

James M. Adams¹ and Daniel Corbett²

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In modelling the shear flow of monodomain liquid crystalline polymers (LCPs) it is usually assumed that the spatial distribution of the shear rate is uniform. This is in contrast to polymer solutions, where highly non-uniform spatial shear rate profiles have been observed. LCPs are often observed to form intricate polydomain structures in the director field. They are observed to form orientational bands under shear flow. The nematic dumbbell model was originally developed to describe the rheology of flow-aligning LCPs. Here we analyse this model using a linear stability analysis to investigate the separate cases of fixed applied stress and fixed applied shear rate. We show that it has a transient flow instability to the formation of a spatially inhomogeneous flow velocity. We compare this instability with the microstructure formation in liquid crystal elastomers. We calculate the spatially resolved flow profile in both fixed stress and fixed shear rate in start up from rest using a model with one spatial dimension to illustrate the flow behaviour of the fluid.

Thursday 11:20 Ulisse

NF22

Shear-banding and Taylor vortices in thixotropic yield stress fluids according a structural parameter model

Mathieu Jenny, Nicolas Louvet, Naima Gaudel, and Sébastien Kiesgen de Richter

LEMTA, Université de Lorraine, Vandœuvre-lès-Nancy 54505, France

Many of yield stress fluids have an inner micro-structure, responsible for the yield stress when an external load is applied, that resists to large-scale rearrangement. The destruction of this micro-structure by the flow is responsible for a complex phenomenon, named thixotropy. The complex behavior of such fluids rises the question of their flow stability in industrial conditions (melting, mass transfers, ...). In that context, we study the flow of a thixotropic yield stress fluid in a Taylor-Couette configuration using a structural parameter modelling. It allows to take into account the microscale kinetic of thixotropic fluids. We use Houska's model [1]. Although the model does not apply to visco-elastic fluids, it allows for a non-monotonic flow curve depending on the breakdown rate of the structural parameter. This non-monotonic behavior is known to induce a discontinuity in the slope of the velocity profile within the flowing material, called shear-banding [2]. Despite shear-banding, the linear stability analysis of the flow shows that the nature of the linear unstable mode is steady and axisymmetric in the large range of the explored parameters [3], as it would be in a simple yield stress fluid [4]. Nevertheless, first experiment results suggest that shear-banding confines the Taylor vortices.

[1] Šesták, J. et al (1983). Journal of Food Engineering, 2(1), 35-49. [2] Divoux, T. et al. (2016). Annual Review of Fluid Mechanics, 48, 81-103. [3] Jenny, M. et al. (2017). Physical Review Fluids, 2(2), 023302. [4] Landry, M. P. et al. (2006). Journal of Fluid Mechanics, 560, 321-353.

Thursday 11:40 Ulisse

NF23

Inertia induced permanent shear band instability of dense amorphous systems

Vishwas V. Vasisht, Magali Le Goff, Kirsten Martens, and Jean-Louis Barrat

Laboratoire Interdisciplinaire de Physique UMR 5588, Centre National de la Recherche Scientifique, University Grenoble Alpes, Saint Martin d'Hères, France

Dense disordered solids, such as emulsions, foams and dense colloidal suspensions, when subjected to shear deformations at a chosen rate, yield and eventually begin to flow. Upon reaching steady state stress values, the system is expected to fluidise and flow homogeneously, but one often observes strong flow instabilities, with parts of the material completely jammed, while other parts of the material flowing at shear rates higher than the imposed rate [1]. This phenomenon is often termed as gradient shear banding, observed both in experiments [2] as well as simulations [3, 4]. In this work we derive a theoretical framework for the appearance of a permanent shear banding instability due to inertial effects. Using a linear stability analysis we estimate the minimum system size necessary to observe a flow instability in the stationary flow of dense particle systems. To verify the theoretical arguments and its predictions, we subject a polydisperse soft sphere system with pure repulsive interactions to a uniform shear deformation using

molecular dynamics simulations. We find that the minimum system size required to accommodate a shear band increases with a decrease in shear rate. For large enough systems, we observe in MD simulations the formation of several shear bands which coarsen into one single shear band in the long time limit.

[1] Bonn, D. et al. (2017). *Reviews of Modern Physics*, 89(3), 035005. [2] Divoux, T. et al. (2016). *Annual Review of Fluid Mechanics*, 48, 81-103. [3] Shrivastav, G. P. et al. (2016). *Journal of Rheology*, 60(5), 835-847. [4] Vasisht, V. V. et al. (2017). arXiv preprint arXiv:1709.08717.

Thursday 12:00 Ulisse

NF24

Thermal shear banding observed in ordinary low molecular weight polymer melts

Laurence NOIREZ

Paris-Saclay Université, laboratoire Léon Brillouin, Gif-sur-Yvette 91191, France

We present real-time micro-thermal measurements of the response of a viscous fluid (low molecular weight Polybutylacrylate melt) submitted to steady-state flow and oscillatory mechanical shear strain in conditions of conventional viscoelastic measurements. We show that thermal changes occur at low shear rates and at the early steps of the applied deformation. A succession of thermodynamic states is identified showing the formation of non-uniform temperature shear bands along the flow or the strain direction. These thermal shear bands indicate the coexistence of cold and warm zones appearing in-phase with the deformation. The synchronism of the temperature variation with the mechanical field highlights a reversible process of elastic type indicating that viscous liquids can exhibit thermoelastic behaviors.

Thursday 12:20 Ulisse

NF25

Effect of non-local stress on shear banding flow in confined geometry : Numerical simulation and rheological measurement

Howon Jin and Kyung Hyun Ahn

Seoul National University, Seoul, Republic of Korea

The nonlocal stress of complex fluid is an extra stress that depends on a spatial variation of shear rate, which is added to the common constitutive relation between the local shear rate and stress. It plays an important role in shear banding instability, where a large spatial gradient of the shear rate exists at the interface between the shear bands. For example, it ensures the stability of the stationary state of shear banding flow. However, there are few studies on the origin of the nonlocal stress. In our previous work, the explicit expression of the nonlocal stress of particulate suspension has been introduced by microscopic calculation on the leading order expansion of force exerted on the particle surface up to sufficiently high order, under arbitrary inhomogeneous flow field. The purpose of this study is a subsequent investigation on the nonlocal stress by using both simulation and experimental approach, based on the previous theoretical work. In the simulation part, the effect of nonlocal stress on the flow behavior of shear banding fluid is investigated. The model fluid has nonmonotonic stress curve under homogeneous shear rate to describe shear banding instability. The simulation is performed under 2 benchmarking flow conditions, shear flow in the parallel rotating disks (PD) geometry, and pressure-driven flow in rectangular channel (RC) geometry. In the experimental part, again, shear flow in PD geometry and pressure-driven flow in RC is investigated by using concentrated alumina suspension which shows shear banding instability. In the shear flow simulation, the estimated stress curve within the nonmonotonic region shows gap size dependence when the fluid undergoes shear banding instability. Similar to the simulation, such gap dependence is also observed in the experiment. The channel flow in both simulation and experiment show well-matched shear banding velocity profiles throughout the different flow conditions.

Thursday 12:40 Ulisse

NF26

Edge fracture versus shear banding in entangled polymeric fluids

Ewan J. Hemingway and Suzanne M. Fielding

Physics, Durham University, Durham, United Kingdom

We perform a comprehensive numerical study of edge fracture in entangled polymeric fluids, with a particular focus on the interaction between edge fracture and the fluid bulk. For fluids with a rather flat (but still monotonically increasing) bulk constitutive curve of shear stress as a function of shear rate, we show that edge fracture causes a pronounced apparent shear banding that invades the fluid bulk to a distance of many gap widths in from the sample edge. To paraphrase this first scenario: "edge fracture causes (apparent) shear banding". For fluids that have a non-monotonic constitutive curve and therefore show bulk shear banding (even in the absence of any edge instabilities), we show that the jump in the second normal stress difference between the bands causes strong edge fracture at the fluid-air interface. To paraphrase this second scenario: "shear banding causes edge fracture". That second scenario is consistent with the insightful analytical predictions of Skorski and Olmsted [*Journal of Rheology* 55, 1219 (2011)], although our numerical study lifts an assumption made to allow analytical progress in that earlier work, which led to some incorrect symmetries in the instability phase diagrams. Taken together, this work shows that shear banding and edge fracture are intimately linked in strongly shear thinning entangled polymeric fluids.

Symposium MN

Micro, Nano Fluidics & Microrheology

Organizers: Nikolai Denkov, Sehyun Shin and Manlio Tassieri

Thursday 9:30 Tritone

MN17

Inertial and elastic flow instabilities in a mixing-separating microfluidic deviceAllysson Domingues, Mahdi Davoodi, Robert J. Poole, and David J. Dennis*Mechanical, materials & aerospace engineering, University of Liverpool, Liverpool, United Kingdom*

Combining and separating fluids has many industrial and biomedical applications such as, biomedical devices, mini or micro-scale mixers and micro-rheometry. In this work we have been investigating the influence of both purely inertial and purely elastic flow instabilities on mixing in a so-called mixing-separating cell micro-geometry using Newtonian and viscoelastic fluids. Our microfluidic mixing-separating cell consists of two straight square parallel channels with flow from opposite directions with a central gap that allows the streams to interact, mix or remain separate (often referred to as the 'H' geometry). A stagnation point is generated at the centre of symmetry due to the two opposed inlets and outlets. Flow-through the microfluidic system was driven under controlled flow rate conditions. Computational Fluid Dynamics simulations were conducted to complement the experimental results. In the experiments, Rhodamine-B was utilised as a fluorescent-sensitive dye in order to obtain flow visualisations. For the Newtonian fluid (70% glycerol-aqueous solution), under creeping flow conditions (Reynolds number [$Re \approx 0$]) the flow is steady, two-dimensional and produces a sharp symmetric boundary between fluids stream entering the geometry from opposite directions. For $Re > 30$, an inertial instability appears which leads to the generation of a central vortex and the breaking of symmetry, although the flow remains steady. As Re increases the central vortex divides into two vortices. Our experimental and numerical investigations both show the same phenomena. The creeping flow of a highly viscoelastic fluid (Polyethylene glycol and Polyethylene Oxide aqueous solution) through the mixing-separating cell micro-geometry undergoes a series of purely-elastic flow transitions from symmetric flow to time-dependent flow depending on the Weissenberg number (Wi). The results suggest that the effect observed can be exploited to enhance mixing in biomedical or other applications.

Thursday 9:50 Tritone

MN18

Inertial micropump in microfluidicsSehyun Shin, Wonwhi Na, Jinsung Kim, and Hoyoon Lee*Mechanical Engineering, Korea University, Seoul, Republic of Korea*

Even though microfluidics has been successfully used in minimizing complicated and onerous processes, the pumping and tubing systems used with it are still immature and need further development. The present study developed a fluttering bar-driven micropump, mounted on a polydimethyl-siloxane microfluidic system. The pump consists of a rectangular magnet bar and a pie-shaped chamber with an inlet and outlet. Through various experiments, the net flow was examined as a function of chamber shape, inlet and outlet channel location, rotating center of the magnet, and rotational speed. Using high-speed camera and image analysis, the net flow was found to be generated by the fluid inertia associated with the varying reciprocating speeds of the bar inside the pie-shaped chamber. Depending on the locations of the inlet and outlet, the cycle time taken to circulate the loop was significantly reduced from 200 to 20 seconds. The flow rate of the micropump ranges from 48-225 $\mu\text{L}/\text{min}$, which is proportional to the rotational speed of the magnetic bar (150-3000 rpm). Using a fluttering bar-driven inertial micropump, the microfluidic system not only provides improved mixing but also eliminates certain problems associated with external tubing and connection.

Thursday 10:10 Tritone

MN19

High throughput viscoelastic ordering of particles in a straight microfluidic channelFrancesco Del Giudice¹, Gaetano D'Avino², and Amy Q. Shen¹¹*Okinawa Institute of Science and Technology, Onna-son, Okinawa 904-0495, Japan;* ²*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

Microfluidics has revolutionized many applications in biomedical engineering, such as particle/cell counting and sorting. Among these applications, interrogation of single particles/cell has recently been achieved by encapsulating cells and functionalised particles in a single picoliter droplet. Unfortunately, in many cases particles and cells can not be encapsulated in the same droplet. This problem could be potentially solved if particles and cells are equally spaced prior the encapsulation, so that the frequency of droplet formation can be synchronized with the frequency of particles and cells entering the encapsulation area. In this work, we show that particles can be equally spaced, i.e. ordered, in a simple straight channel by introducing viscoelasticity in the suspending liquid. We study the effect of flow rate, channel length, particle concentration, and fluid rheology on the particle ordering. We employ two hyaluronic acid solutions at different concentrations in phosphate buffer saline (PBS). The first testing fluid is elastic with almost constant-viscosity, while the second fluid exhibits both elastic and shear-thinning features. We find that particles of 20 μm in diameter flowing at 50 $\mu\text{L}/\text{min}$ and 100 $\mu\text{L}/\text{min}$ in a straight square-shaped microchannel with height of 100 μm can be equally spaced only when suspended in the shear-thinning liquid, at a given particle concentration. We do not observe viscoelastic ordering at low particle concentrations since particles cannot interact with each other. Particles suspended in the near constant-viscosity liquid focus both on the centerline and the wall, thus preventing particle ordering. Since both particle concentration and flow rate are relatively high, a throughput up to ~ 15000 particles/s is also achieved, offering great potentials for rapid healthcare applications.

Thursday 10:30 Tritone

MN20

Tuning particle translation and rotation in shallow microfluidic channels via particle shape – experiments and simulations

Rumen N. Georgiev¹, Bram P. Bet², Sela Samin², William E. Usal³, and Burak Eral¹

¹Process and Energy, TU Delft, Delft 2628 CB, The Netherlands; ²Cond-Matter Theory, Stat & Comp Phys, Universiteit Utrecht, Utrecht, Utrecht 3584 CE, The Netherlands; ³Max Planck Institute for Intelligent Systems, Stuttgart, Baden-Württemberg 70569, Germany

Deeper understanding of particle motion in microfluidic devices would unlock new methods for continuous, high throughput separation of cells and crystal polymorphs. Particles in confined flow can interact hydrodynamically with each other or with surrounding surfaces, altering their trajectories. Recent studies focus on droplets as a model system to gain insight into hydrodynamic interactions in microfluidic flows [1]. However, droplets lack the many degrees of freedom needed to tailor a microparticle's trajectory. Particles with controllably broken symmetry present an ideal candidate for exploration of the microfluidic playground. We consider mirror-symmetric particles with varying shape produced via stop flow lithography in a shallow, quasi-2D microfluidic channel. Once produced, a particle is subjected to creeping flow and its motion is tracked [2]. Thin lubrication layers separating the particle faces from the horizontal walls give rise to a strong drag on the particle, which lags the surrounding flow. We model the observed behaviour by treating the fluid in a quasi-2D Brinkman formalism, averaging the flow over the channel height. The forces and torque on a particle are calculated via a two-dimensional finite element scheme, with the effect of the horizontal walls incorporated by adding an effective drag force. Exploiting the linearity of Stokes flow, we decouple translation and rotation and achieve quantitative agreement with the experimentally observed motion. Regardless of their detailed shape, all studied mirror-symmetric particles exhibit the same qualitative motion - rotation about their z-axis and dampened oscillation in the vorticity direction - akin to the one recently reported [2]. Furthermore, scaling the trajectories of all considered shapes by their respective characteristic translational and rotational timescales yields a single trajectory, universal to axisymmetric particles.

[1] Beatus, T. et al. (2017). Chemical Society Reviews, 46(18), 5620-5646. [2] Usal, W. E. et al. (2013). Nature communications, 4, 2666.

Symposium SM

Polymer Solutions & Melts

Organizers: Yuichi Masubuchi, Angel Moreno and Daniel Read

Thursday 11:20 Tritone

SM17

Molecular rheology of entangled polymeric fluids: understanding bulk flow behavior based on single molecule dynamics

Mohammad Hadi Nafar Sefiddashti, Brian J. Edwards, and Bamin Khomami

¹Chemical and Biomolecular Engineering, University of Tennessee, Knoxville, TN 37996-2200, United States

In the past several years we have performed extensive Non-Equilibrium Molecular Dynamics simulations of atomistically-detailed monodisperse PEs in simple shear and planar extensional flows including a mildly entangled C₄₀₀H₈₀₂, a moderately entangled C₇₀₀H₁₄₀₂, and a fully entangled C₁₀₀₀H₂₀₀₂. In this presentation, the simulation results particularly in regards to molecular rheology of this class of fluids will be used to: 1) determine the dominant molecular time scales at various deformation rates, 2) assess the fidelity of advanced reputation based models in predicting the flow dynamics of entangled polymeric liquids particularly at high deformation rates, and 3) to develop experimental protocols for accurate measurement of extensional viscosity of this class of fluids.

Thursday 11:40 Tritone

SM18

Stress relaxation of polymer melts under fast shear flow: a simulation study

Jun-ichi Takimoto and Sathish K. Sukumaran

Department of Polymeric and Organic Materials Engineering, Yamagata University, Yonezawa, Yamagata 992-8510, Japan

About 20 years ago, Marrucci and Ianniruberto have proposed that, under fast flow, the relaxation of the orientation and stress in polymeric liquids is accelerated since polymer chains are pulled out of entanglements by the flow. This CCR (Convective Constraint Release) mechanism is now widely accepted and considered as an essential ingredient of polymer dynamics. Several authors conducted dynamic viscoelastic measurements under shear flow and have shown that the stress relaxation is indeed accelerated by the shear flow. In the case of the dielectric relaxation (of the type-A polymers), however, experiments have shown that there is little acceleration by the shear flow. In order to get insight into the reason of this discrepancy, we are conducting simulation study of the stress and dielectric relaxation under shear flow by using a slip-link model and coarse-grained molecular dynamics (MD). In the case of entangled polymers, our simulation shows *both* stress and dielectric relaxation are accelerated by the shear flow, being consistent with CCR. Recently, however, Unidad and Ianniruberto have shown that, due to the rotation component of the shear flow, a constitutive model *without* CCR can also predict an apparent acceleration of the stress relaxation by the shear flow. We have conducted MD simulations with chains *shorter* than entanglement length (i.e., no CCR), and found that both stress and dielectric relaxations are still accelerated. In the case of stress relaxation, the relaxation modulus $G(t)$ under shear flow shows an undershoot ($G(t) < 0$) and the shear strain at which $G(t)$ crosses zero is close to one independent of the shear rate. This suggests that, in the case of entangled melts, at least part of the acceleration is not due to CCR but caused by the rotating nature of the shear flow (although why experimentally no acceleration is observed for dielectric relaxation is still unknown). Relation with the rotation of individual chains under shear flow will also be discussed.

Thursday 12:00 Tritone

SM19

Stress undershoot of entangled polymers under fast startup shear flows in primitive chain network simulations

Yuichi Masubuchi¹, Giovanni Ianniruberto², and Giuseppe Marrucci²

¹*Department of Materials Physics, Nagoya University, Nagoya, Japan;* ²*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

In this study, viscosity growth of entangled polymers under startup of fast shear flows was investigated by means of primitive chain network simulations. In particular, we focused on the undershoot following the well-known overshoot. The simulations reasonably reproduced the viscosity growth data reported in the literature for polystyrene melts. To investigate the origin of the observed undershoot, stress was decomposed into orientational and stretch contributions through a decoupling approximation. The decoupled results show a tiny undershoot in both orientation and stretch. Molecular tumbling was also monitored, both for single molecules and in terms of an average end-to-end orientation angle. Results appear to confirm that tumbling causes the viscosity undershoot, consistently with the suggestion of Costanzo et al [1].

[1] Costanzo, S. et al. (2016). *Macromolecules*, 49(10), 3925-3935.

Thursday 12:20 Tritone

SM20

Exploring polymeric materials with multiscale simulations for interface engineering

Giuseppe Milano

Organic Materials Science, Yamagata University, Yonezawa, Japan

In this talk I will show results of coarse-grained models based on a atomic or a molecular representation very close to atomic scale. These results include, recent models combining particle and continuum representations. In particular, descriptions based on combination of molecular models and field theory or molecular models and finite elements methods (FEM). This feature of coarse-grained models allowed a quantitative description of the polymeric materials that in several cases led to a better understanding and to a rational design of new materials. Several examples ranging from polymer melts, to nanocomposites applied in organic electronics, sensors, interaction of synthetic polymers and biomembranes, nanoparticles based materials, hydrogen bonding in synthetic polymers will be given [1-8].

[1] Milano, G., & Kawakatsu, T. (2010). *The Journal of chemical physics*, 133(21), 214102.. [2] Byshkin, M. S. et al. (2015). *Sensors and Actuators B: Chemical*, 211, 42-51. [3] Zhao, Y. et al. (2016). *Nanoscale*, 8(34), 15538-15552. [4] De Nicola, A. et al. (2015). *RSC Advances*, 5(87), 71336-71340. [5] De Nicola, A. et al. (2014). *Journal of chemical theory and computation*, 10(12), 5651-5667. [6] Milano, G. et al. (2011). *The Journal of Physical Chemistry C*, 115(31), 15154-15163. [7] De Nicola, A. et al. (2014). *Physical Chemistry Chemical Physics*, 16(11), 5093-5105. [8] De Nicola, A. et al. (2017). *The Journal of Physical Chemistry B*, 121(14), 3162-3176.

Thursday 12:40 Tritone

SM21

Computational design of nanostructured polymer materials: atomistic simulations of self-assembled miktoarm star copolymers

Petra Bacova¹, Emmanouil Glynos², and Vagelis Harmandaris¹

¹*Institute of Applied and Computational Mathematics, Foundation for Research and Technology-Hellas, Heraklion, Greece;* ²*Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, Heraklion, Greece*

We present a detailed simulation methodology for the study and the design of nanostructured polymeric particles [1]. By means of atomistic molecular dynamics simulations, we examine the structural and dynamical behavior of mikto-arm star-like copolymers in a single-molecular lever and when incorporated in a selective medium. The miktoarm stars are composed of immiscible and dynamically asymmetric arms of poly(styrene), PS and poly(ethylene oxide), PEO. Starting with single-molecule simulations, we varied systematically the functionality and the arm length to explore the effect of macromolecular architecture on the star intramolecular structure. A variety of nanostructured objects was observed, ranging from Janus to patchy particles. Apart from the functionality effects, the intramolecular segregation is dictated by the specific interaction in the atomic level as well as the different flexibility of the blocks; factors which cannot be accurately described by typical coarse-grained simulations. Diluted in oligomeric PEO chains, the miktoarm stars self-assemble into interconnected networks similar to those observed in recent experimental work on analogous miktoarm stars [2]. Our study provides a detailed picture of the segmental dynamics both at the intramolecular level and when the polymer particles are self-assembled, which is not easily acquired by experimental techniques. The monomers close to the core relax at a significantly slower rate than those away from the core, while the magnitude of the slowing-down depends on the functionality as well as on the dynamical environment (homopolymer vs. copolymer stars). The structural and dynamical heterogeneities are also discussed in relation to the glass transition temperature of the model systems, and compared against available experimental data [2].

[1] P. Bacova, E. Glynos, V. Harmandaris; to be submitted. [2] Glynos, E. et al. (2017). *Macromolecules*, 50(12), 4699-4706.

Symposium NF

Non Newtonian Fluid Mechanics & Flow Instabilities

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Thursday 9:30 Nettuno 1

NF52

Stable simulation of viscoelastic fluid flow using integral modelsMartien A. Hulsen and Patrick D. Anderson*Eindhoven University of Technology, Eindhoven, The Netherlands*

New constitutive models for viscoelastic fluids are often formulated in terms of memory integral equations. For example, the constitutive model for complex fluids with a power-law like spectral behaviour of Jaishankar & McKinley [1] is written in the form of a K-BKZ integral model. However, development of stable finite element methods for viscoelastic fluids has mostly been focussed on differential models. Great progress has been achieved in the field of numerical simulation of differential models. The introduction of stabilisation techniques such as SUPG, (D)EVSS-G, log-conformation, and velocity-stress decoupling schemes for zero solvent viscosity, has made it possible to solve many problems at much higher Weissenberg numbers for a large class of models of the differential type. In this talk, new developments in the deformation fields method [2] will be presented that will give this method numerical stability properties that are comparable to state-of-the-art methods for differential models. Results will be shown on the time-dependent stability of Couette flow and the flow around a cylinder confined between two flat plates.

[1] Jaishankar, A., & McKinley, G. H. (2014). *Journal of Rheology*, 58(6), 1751-1788. [2] Hulsen, M. A. et al. (2001). *Journal of non-newtonian fluid mechanics*, 98(2-3), 201-221.

Thursday 9:50 Nettuno 1

NF53

Theoretical & computational modelling of compressible viscoelastic fluidsAlex T. Mackay*Mathematics, Cardiff University, Cardiff CF24 3PD, United Kingdom*

Compressible and non-isothermal effects are often ignored when modelling flows of non-Newtonian fluids. The additional equations governing density and temperature transport increase the complexity of the governing system of nonlinear partial differential equations which adds to the challenge of devising efficient and stable numerical schemes. The generalised bracket method [1] provides a strong theoretical framework for deriving governing equations of viscoelastic fluids based on energy/entropy formulation. Taylor-Galerkin pressure correction schemes coupled with Discrete Elastic Viscous Stress Splitting (DEVSS) stabilisation enable accurate solutions to be generated for a wide range of flow parameters. The derivation of the governing equations is described and some numerical results on benchmark problems are presented. In particular, the flow in the unit square (lid-driven cavity problem) is considered for a range of Reynolds, Weissenberg and Mach numbers and the influence of compressibility and viscoelasticity on flow characteristics are assessed.

[1] Edwards, B. J., & Beris, A. N. (1991). *Journal of Physics A: Mathematical and General*, 24(11), 2461.

Thursday 10:10 Nettuno 1

NF54

Sparse grids - an approach to reduce the complexity of multiscale simulationsAlexander Rüttgers*Simulation and Software Technology, German Aerospace Center, Cologne, Germany*

A computationally efficient algorithm for multiscale simulations of non-Newtonian fluids is presented. This novel approach bases on a sparse grid discretization and extends previous simulations with a FENE dumbbell model in three-dimensional square-square contraction geometries [1]. Multiscale simulations lead to model equations of high dimensionality. Depending on the number of spring segments, the configuration space for the polymer model has up to twenty dimensions. Therefore, multiscale simulations suffer from the curse of dimensionality and either require massively parallel computations or a problem-adapted approach such as sparse grids. In this talk, we compare our multiscale simulation with results from literature and obtain a good agreement. Furthermore, we demonstrate that our approach reduces the complexity of multiscale simulations by one order of magnitude [2].

[1] Griebel, M., & Rüttgers, A. (2014). *Journal of Non-Newtonian Fluid Mechanics*, 205, 41-63. [2] Rüttgers, A., & Griebel, M. (2018). *Applied Mathematics and Computation*, 319, 425-443.

Thursday 10:30 Nettuno 1

NF55

Fluid – spherical particles interaction in confined domains: the glass bead gameIstvan Mogos and Corneliu Balan*REOROM Laboratory, University Politehnica, Bucharest 060042, Romania*

Motto: Scientific work might be also considered as a game for researchers, but a serious game ... "a play of imaginations and ideas" (Kant), "a language game" (Wittgenstein) or, why not, a "glass bead game" (Hesse). The present study was inspired by the Hermann Hesse's writing *The glass bead game*. In this novel is allusive proposed to link mathematics (science) and music (art) by an intellectual sophisticated game, most probably with the origin in Pythagoras music of spheres (continued today by the string theory!). Our work started as a game, playing with spheres in fluids and observing how the spheres' configuration is influenced by the local hydrodynamics. Finally, the study is concerned with the investigations of simple and complex flows generated in confined geometries (cylinders of circular cross section) by moving spheres (beads). The experiments are expected to bring scientific value and novel information on two directions: I. The control of spheres packing in layers by the induced hydrodynamics in a confined domain and the determination of the resulting skeleton permeability. Spheres are let falling free in glass cylinders filled with viscous or

viscoelastic fluids. There are observed: (i) the dependence of the resulting spheres packing permeability on the rheological properties of the tested fluids, (ii) the influence of fluid elasticity on the dynamics of the flow inside the cylinders. II. The analysis of the viscous and viscoelastic flows induced by accelerated spheres in confined domains. One magnetized sphere is let falling free in a glass cylinder filled with viscous or viscoelastic fluid. Under a magnetic field influence the falling velocity of the sphere is modified. There is investigated the influence of the sphere's accelerating/decelerating on the induced flow pattern within the cylinder, in relation to the rheological properties of the fluids.

Thursday 11:20 Nettuno 1

NF56

A cut finite element method for multi-phase viscoelastic flows

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In this presentation, we will introduce a cut finite element method for three field Stokes' flows [1] and multi-phase viscoelastic flows. In our scheme, which is based on CutFEM [2], the interface between two liquids is described by a level set function whose zero level set cuts arbitrarily through a fixed background mesh. In intersected elements, the physical boundaries of each liquid phase are respected by integrating the weak formulation only over parts of the elements that are covered by the respective fluids. Additionally, intersected elements are doubled to allow for discontinuities in the pressure and kinks in the velocity solution inside elements. Our method is stable independent of the cut location due to so-called ghost penalties [3-5], which are applied along the edges of intersected elements. In the presentation, we will demonstrate the capability of our method on several multi-phase flow problems such as microfluidic flows.

[1] Burman, E. et al. (2015). *SIAM Journal on Scientific Computing*, 37(4), A1705-A1726. [2] Burman, E. et al. (2015). *International Journal for Numerical Methods in Engineering*, 104(7), 472-501. [3] Burman, E. (2010). *Comptes Rendus Mathématique*, 348(21-22), 1217-1220. [4] Shrivastav, G. P. et al. (2016). *Journal of Rheology*, 60(5), 835-847. [5] Vasisht, V. V. et al. (2017). *arXiv preprint arXiv:1709.08717*.

Thursday 11:40 Nettuno 1

NF57

A two-phase viscoelastic solver considering a diffuse interface model

Konstantinos Zografos¹, Alexandre M. Afonso², Robert J. Poole¹, and Mónica S. N. Oliveira³

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The performance of a two-phase solver that is implemented on top of an in-house viscoelastic single-phase solver [1] is presented. An interface capturing method is considered, where a diffuse interface model based on the Phase-Field method is coupled with the equations of motion. More specifically the transport of the binary fluid is described by continuity, momentum and the convective Cahn-Hilliard equations [2]. The advantage of the current approach is that the interface between the two fluids adopts a continuum approach which smooths the inherent discontinuities, compared to the sharp interface models [3]. Therefore, studies that are related to morphological changes of the interface, such as droplet breakup and coalescence, are feasible. This, together with the computational challenges raised when simulating flows of complex fluids, make Phase-Field method a suitable approach for examining the interfacial dynamics in complex multiphase systems. A range of test cases are examined in order to validate our implementation, considering both Newtonian and viscoelastic fluids. Initially, the efficiency of our implementation is investigated by approximating the Young-Laplace equation. Then, more complex problems are considered such as the Rayleigh-Taylor instability, the oscillation of a square droplet, the rising bubble and the deformation of a droplet under constant shear. For all these cases the two-phase solver manages to predict the expected dynamics and presents an overall good performance. Especially for the Rayleigh Taylor instability which presents the most complex interfacial patterns among the investigated cases, our implementation is able to capture them with very good accuracy.

[1] Oliveira, P. J. et al. (1998). *Journal of Non-Newtonian Fluid Mechanics*, 79(1), 1-43. [2] Jacqmin, D. (1999). *Journal of Computational Physics*, 155(1), 96-127. [3] Kim, J. (2009). *Computer Methods in Applied Mechanics and Engineering*, 198(37-40), 3105-3112.

Thursday 12:00 Nettuno 1

NF58

Simulating the dispensing of complex rheological fluids on arbitrary geometries using the immersed boundary method

Simon Ingelsten, Johan Göhl, Andreas Mark, and Fredrik Edelvik

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Processes that include extrusion and application of fluids with complex rheological properties are common in industrial applications, including seam sealing, gluing and additive manufacturing. Simulation tools that can be used to simulated such processes in an accurate and effective way are therefore of high relevance. In this work a framework is presented where the application of complex fluids along prescribed paths can be simulated. The flow solver IPS IBOFlow is used to solve the flow equations, which are discretized on an octree grid that is automatically and dynamically generated, and refined at boundaries of geometries and phases. The boundary conditions imposed on internal geometries are treated with the immersed boundary method, which in combination with the octree grid enables simulations on arbitrary and moving geometries. The two-fluid flow of the extruded material is modeled with the Volume of Fluids method and the material is injected into the computational domain with prescribed inlet velocity imposed using the immersed boundary method. The rheology models considered may be divided in two categories. The first consists of models in which rheological properties influence the flow through a varying viscosity. These models include simpler shear thinning

models, such as the Bingham and Carreau models, and temperature dependent models. Viscous models also include the more complex thixotropic models, where the shear rate history of fluid elements also influences the local viscosity. The second category includes viscoelastic models which describe the full stress tensor, such as the PTT or the FENE models. These models can describe the storage of elastic energy caused by the fluids deformation history, which purely viscous models cannot. Examples will be presented with simulation of shear thinning seam sealing material, extrusion of viscoelastic glue and additive manufacturing of with highly temperature dependent liquid metal, also including phase transition.

Thursday 12:20 Nettuno 1

NF59

Linear stability and transient behaviour of viscoelastic fluids in boundary layers

Martina Cracco, Christopher Davies, and Timothy N. Phillips

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The behaviour of many real fluids is well described by Navier- Stokes theory. This theory is based on the assumption of a Newtonian constitutive equation. More specifically, the extra-stress tensor can be expressed as a linear, isotropic function of the components of the velocity gradient. Many common fluids, such as water and air can be assumed to be Newtonian. However, many rheologically complex fluids such as polymer solutions, soaps, blood, paints, shampoo, ketchup are not adequately described by a Newtonian constitutive equation, which does not take into account any relaxation and retardation phenomena. Viscoelastic fluids are examples of non-Newtonian fluids, they exhibit both viscous and elastic properties when undergoing deformation. One of the first class of material models proposed consists of fluids of differential type. The fact that this class of fluids cannot take account of stress relaxation may suggest that they are suitable to model materials where relaxation effects are insignificant, such as slurry fluids and fluids involved in the food industry. First, we consider a subclass of differential type fluids known as Rivlin-Ericksen fluids of second grade. The aim of the research is to understand the stability behaviour of such fluids in boundary layers. A simple two-dimensional configuration of a flow over a semi-infinite wedge is considered. A linear stability analysis leads to a modified Orr-Sommerfeld equation that is solved by a Chebyshev collocation method. The numerical experiments conducted show that elasticity in this model has a stabilising effect. A second analysis shows that, when a three dimensional configuration is considered, elasticity can induce an instability that results in generation of streamwise vortices. Furthermore, results on transient behaviour show that elasticity generally increases the energy of the perturbations over short time periods. The stability analysis is extended to more complicated models of viscoelastic fluids.

Thursday 12:40 Nettuno 1

NF60

The singularity of the Oldroyd-B model for the viscoelastic flows past a cylinder and past a sphere

Kostas D. Housiadas

Mathematics, University of the Aegean, Karlovassi, Samos 83200, Greece

We investigate analytically the steady viscoelastic creeping flows of an incompressible and isothermal Oldroyd-B fluid past a cylinder and past a sphere. The method of solution of the governing equations is a regular perturbation scheme with the small parameter being the Weissenberg number (Wi). The solution for all the dependent flow variables is expanded in a standard power-series form in terms of Wi . These expressions are substituted into the governing equations and a sequence of systems of differential equations accompanied with the suitable boundary conditions, results. The equations are solved analytically up to very high order in Wi , and thus the final solution for all the dependent variables is found in series form with many terms. The accuracy of the obtained solutions increases when the results are suitably processed with non-linear methods which accelerate the convergence of series, such as Shanks' transformation and Padé-type approximants. The new transformed, and improved, expressions reveal a pole of the solution at a critical Weissenberg number, at which divergence occurs. Consequently, the Oldroyd-B model is not suitable to model viscoelastic phenomena at relatively large values of the Weissenberg number. The singularity is removed when other, more complicated, constitutive models, such the Giesekus, FENE-P and Phan-Thien & Tanner models, are used.

Symposium SG

Solids, Glasses, & Granular Materials

Organizers: Philippe Coussot, Joe Goddard and Luigi Grassia

Thursday 9:30 Nettuno 2-3

Keynote SG18

Acousto-Rheology: probing and triggering of unjamming in dense granular media

Xiaoping Jia, Julien Leopoldes, and Arnaud Tourin

Institut Langevin, ESPCI, Paris, Paris 75238, France

Laboratory studies of granular friction have emerged as a powerful tool for investigating dynamics of seismic faults [1], including dynamic triggering of earthquakes and landslides [2, 3]. Advances in granular physics have paved the way for understanding how elastic waves trigger fault slips. The emerging view is that dynamic perturbation of sheared gouge materials causes an elastic softening up to a material failure, which could be seen as unjamming transition by acoustic fluidization [4, 5]. Here we report a series of experiments conducted in granular solids. First, we investigate the shear instability in confined granular media by acoustic probing. Decrease of the shear wave velocity and development of the fabric anisotropy are observed prior to failure. We also find that the correlation function of the multiply scattered coda waves is very sensitive to details of the stick-slip, such as rearrangements of granular networks during shear banding [6]. Next, we study the fluidization of a granular solid by the nonlinear acoustic pumping. Two regimes are found when the amplitude of vibration increases: in the first we observe a significant shear modulus weakening but without visible grain rearrangement, while in the second there is a plastic rearrangement of grains accompanied with the modulus decrease up to 85% [7]. Finally, we show that such mechanisms could explain the triggering of granular avalanches by small-

amplitude ultrasound that acoustically lubricates the contact area and reduce the apparent friction coefficient between grains [8] without causing rearrangement via dilatancy.

[1] Marone, C. (1998). Annual Review of Earth and Planetary Sciences, 26(1), 643-696. [2] Gombert, J. et al. (2001). Nature, 411(6836), 462. [3] Johnson, P. A., & Jia, X. (2005). Nature, 437(7060), 871. [4] Jia, X. et al. (2011). Physical Review E, 84(2), 020301. [5] Melosh, H. J. (1996). Nature, 379(6566), 601-606. [6] Khidas, Y., & Jia, X. (2012). Physical Review E, 85(5), 051302. [7] J. Brum et al, to be submitted. [8] J Léopoldès, J. et al. (2013). Physical review letters, 110(24), 248301.

Thursday 10:10 Nettuno 2-3

SG19

Dissipation potentials and gradient regularization of granular Hadamard instability

Joe Goddard

Mechanical and Aerospace Engineering, University of California, San Diego, La Jolla, CA 92093-0411, United States

This presentation is concerned with the viscoplastic Hadamard (short wavelength) instability of the so-called " $\mu(I)$ " model of dense rapidly-sheared granular flow, as revealed recently by Barker et al. [1]. In particular, the present talk summarizes how one may achieve stabilization by higher velocity gradients based on an enhanced-continuum model that is the dissipative analog of the Van der Waals-Cahn-Hilliard equation of equilibrium thermodynamics, as shown recently by Goddard & Lee [2]. This model involves a dissipative hyper-stress, with surface viscosity arising as counterpart of elastic surface tension. This allows for a description of diffuse shear bands as the rough analog of the diffuse interfaces of equilibrium thermodynamics. The latter paper also presents a more comprehensive linear stability analysis, including convective (Kelvin) wave-vector stretching by the base flow that leads to asymptotic stabilization of the non-convective instability found by Barker et al. This suggests a theoretical connection between their non-convective instability and the loss of generalized ellipticity in the quasi-static field equations. Apart from its theoretical interest, the present work may suggest stratagems for the otherwise difficult numerical simulation of continuum field equations involving Hadamard-unstable viscoplasticity.

[1] Barker, T. et al. (2015). Journal of Fluid Mechanics, 779, 794-818. [2] Goddard, J. D., & Lee, J. (2017). Journal of Fluid Mechanics, 833, 302-331.

Thursday 10:30 Nettuno 2-3

SG20

3D simulation of dense granular flow in a rotating drum

Angelica Maria G. Arseni, Gaetano D'Avino, Francesco Greco, and Pier Luca Maffettone

Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

Granular materials, i.e., materials made by solid particles in contact, are encountered in several fields and applications, e.g., pharmaceuticals, food industries, polymers processing, geophysics. When subjected to external forces, granular materials exhibit complex pattern-forming behaviors; numerical simulations can then provide a useful tool to understand the physics underlying the dynamics of these materials. In most of the works available in the literature, the commonly adopted numerical approach to study granular materials is the Discrete Element Method (DEM), where the material is modeled as an assembly of rigid particles, and the interactions among particles are explicitly considered. Although DEM has the advantage to describe the discrete nature of the flow, a relatively limited number of particles can be managed. To overcome this drawback, a continuum approach is desirable. In this work, we present 3D Finite Volume (FV) simulations of dense granular flow inside a rotating cylinder, adopting the visco-plastic Jop-Porterre-Pouliquen constitutive model [1] for the granular medium stress tensor. The effects of the cylinder aspect ratio, the drum angular velocity, the particle dimensions (as a parameter in the constitutive equation), and the slip between the drum wall and the particles are investigated. The results obtained from our simulations for free-surface velocity, axial velocity, and thickness of the flowing layer, are also compared with experimental results available in the literature [2-4].

[1] Jop, P., Forterre, Y., & Pouliquen, O. (2006). A constitutive law for dense granular flows. Nature, 441(7094), 727. [2] Alexander, A. et al. (2002). Powder Technology, 126(2), 174-190. [3] Pohlman, N. A. et al. (2006). Physical review E, 74(3), 031305. [4] Félix, G. et al. (2007). The European Physical Journal E, 22(1), 25-31.

Thursday 11:20 Nettuno 2-3

SG21

Granular column collapse in fluid: combined CFD-DEM modelling and experimental validation

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The purpose of the study is to investigate granular column collapse in fluid experimentally and numerically. Experiments on granular column collapse in water were conducted and Voronoi image processing technique was employed to measure velocity profile and surface profile of granular flow in water as well as the flow rate at the outlet. In addition, a two-phase flow discrete element method (combined CFD-DEM modeling) was proposed to simulate the corresponding experiments. In the combined CFD-DEM simulation, a background damping model was incorporated to dissipate excessive energy of particulate system induced by traditional DEM simulations. The study shows that the simulations produce reasonable agreement with experiments for the velocity profiles, flow rate at the outlet, translational velocity field and surface profiles. The validated numerical model was further used to explore internal physical properties of granular assembly. The internal flow characteristics are presented and discussed in this paper.

Thursday 11:40 Nettuno 2-3

SG22

Finite shear rate critical point in a mesoscopic model of flowing disordered materialsMagali Le Goff¹, Vishwas V. Vasisht¹, Eric Bertin², and Kirsten Martens²¹Laboratoire Interdisciplinaire de Physique, University Grenoble Alpes, Saint Martin d'Hères, France; ²Laboratoire Interdisciplinaire de Physique UMR 5588, Centre National de la Recherche Scientifique, Saint Martin d'Hères, France

Yield stress materials such as emulsions, foams, granular materials, colloidal glasses etc., even though they differ in their microscopic nature, share many common features. In particular, their flow properties are characterized by a yielding transition in the limit of vanishing shear rates [1] and the existence of a shear banding instability associated to a non-monotonic flow curve [2]. In these systems, critical behaviors have been extensively studied at the yielding transition, but criticality at finite shear rate is still poorly understood and has only been addressed in the case of vibrated frictional granular materials in a recent work [3], where an external mechanical vibration induces a transition from a non-monotonic to a monotonic flow curve, accompanied by critical-like fluctuations of the macroscopic shear rate. In this study we investigate the role of an external agitation on the flow of yield stress materials exhibiting a non-monotonic flow curve, and study the induced transition from a non-monotonic to a monotonic flow curve, associated to the disappearance of a shear-band instability. Within a minimalistic mesoscopic model that incorporates the local elasto-plastic dynamics of yield stress materials [4], we probe two different phenomenological models of agitation and show that although they can lead to different rheological behaviors, the agitation-induced critical point shares similar features in the two cases and also with the case of vibrated frictional grains [3]. These results suggest that these types of finite shear rate critical transitions are not only dictated by the microscopic dynamics, but may share generic features.

[1] Lin, J. et al. (2014). Proceedings of the National Academy of Sciences, 111(40), 14382-14387. [2] Coussot, P., & Ovarlez, G. (2010). The European Physical Journal E, 33(3), 183-188. [3] Wortel, G. et al. (2016). Physical review letters, 117(19), 198002. [4] Picard, G. et al. (2005). Physical Review E, 71(1), 010501.

Thursday 12:00 Nettuno 2-3

SG23

Rheological principles of development self-healing ceramic based composite materials with extreme dynamic strengthLászló A. Gömze¹ and Ludmila N. Gömze²¹R and D of New Materials and Technologies, IGREX Engineering Service Ltd, Miskolc H-3530, Hungary; ²IGREX Engineering Service Ltd, Miskolc H-3530, Hungary

It is obvious that ceramic materials have different modules of elasticity and melting temperatures depending on their chemical compositions and morphological and crystalline structures. Because of these the composite materials created from components and particles of different melting temperatures and modules of elasticity have better ability to absorb and dissipate kinetic energy during dynamic beats and high speed collisions. Examining the behaviors of different ceramics and CMCs under high speed collisions in several years the authors have confirmed the advantages of hetero-modulus, hetero-viscous and hetero-plastic complex material systems. Applying the rheo-mechanical principles the authors first have developed new corundum-matrix composite materials reinforced with Si₂ON₂, Si₃N₄, SiAlON and AlN submicron and nanoparticles. These new nanoparticles reinforced hetero-modulus CMCs have excellent dynamic strength during their collisions with high density metallic bodies with speeds of 1000 m/sec or more. During the high energy collisions the phase transformation of submicron and nanoparticles of alpha and beta silicone-nitride crystals into diamond-like cubic c-Si₃N₄ particles were observed. Based on the rheological principles and the energy engorgement by fractures, heating, melting and phase transformations in solid stages of components the authors successfully developed several new hetero-modulus, hetero-viscous and hetero-plastic complex materials with extreme dynamic strength. These new composite materials generally are based on traditional ceramic matrixes (Al₂O₃x2SiO₂, Al₂O₃, Si₃N₄, SiC), and non-ceramic components with different melting temperatures and modules of elasticity. To prepare new self-healing CMCs with increased dynamic strength in additions to the ceramic matrix both materials with relatively low (graphite, Mg, Al, Ti, Si) and high (borides, nitrides and carbides) modules of elasticity were used by the authors.

Thursday 12:20 Nettuno 2-3

SG24

Non-uniform flow in soft glasses of DNA-virus suspensionsKyongok Kang¹, Hartmut Kriegs¹, John Marakis², Dimitris Vlassopoulos², and Jan Dhont¹¹ICS-3, Soft Condensed Matter, Forschungszentrum Juelich, Juelich, NRW 52425, Germany; ²Department of Materials Science and Technology, FORTH, University of Crete, Crete, Greece

Recently, long, thin and highly charged DNA-virus rods (fd-virus particles) were found to vitrify in aqueous suspensions at low ionic strength [1-3]. The glass transition of these long-ranged repulsive rods occurs at a concentration far above the isotropic-nematic coexistence region and is characterized by the unique arrest of both the dynamics of domains that constitute the chiral-nematic orientational texture, as well as individual rods inside the domains. Hence, two relevant length scales exist: the domain size of a few hundreds of microns, and the rod-cage size of a few microns, inside the domains. We show that the unique dual dynamic arrest and the existing of two widely separated length scales imparts an unprecedented, highly heterogeneous flow behavior with three distinct signatures [4]. At low shear rates we observe fractured flow, which is attributed to the interactions between the internally frozen domains. On increasing the shear rate, the fractured plug flow changes to a shear-banded flow profile due to the stress response of the kinetically arrested aligned rods within the domains. Shear-gradient banding thus occurs due to the strong thinning of the uniform chiral-nematic phase within the domains, i.e., complying with the classic shear-banding scenario, as evidenced by a stress plateau in the flow curve. Finally, a linear (uniform) velocity profile is found at the highest shear rates. Moreover, it is argued that the origin of shear banding in soft-particle glasses with long-ranged repulsive interactions is fundamentally different from that of hard-particle glasses with short-ranged repulsive interactions.

[1] Kang, K., & Dhont, J. K. G. (2013). Physical review letters, 110(1), 015901. [2] Kang, K., & Dhont, J. K. (2013). Soft Matter, 9(17), 4401-4411. [3] Kang, K. (2014). Soft matter, 10(18), 3311-3324. [4] Dhont, J. K. G. et al. (2017). Physical Review Fluids, 2(4), 043301.

Thursday 12:40 Nettuno 2-3

SG25

Time-dependent behavior of polymer-metal composite stripe for magnetic encoders

Oseli Alen¹, Aulova Alexandra¹, Praprotnik Jan², and Slemenik Perše Lidija¹

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Advanced rotary and linear motion sensors usually utilize magnetic tracks for encoding information. They are composed of steel substrate as structural support and polymer-metal composite stripes as information carriers. During processing/manufacturing polymer-metal composite is subjected to external loads causing time-dependent responses (decaying stress or increasing deformation) which profoundly affect material dimension and therefore lower the accuracy of sensor systems. Within this research we have analyzed (i) how processing of polymer-metal composite material, i.e. calendaring, affects its mechanical properties by observing changes of storage E' through the thickness and length of the stripe (Agilent G200 Nanoindenter XP), and (ii) how manufacturing procedure, i.e. unrolling and cutting of the stripe, affects its dimensional changes related to time-dependent behavior of such material by simulating unrolling with relaxation tests (applied strain during unrolling) and cutting with creep tests (stress release due to material relaxation) utilizing uniaxial relaxation and creep experiments (Haake Mars II rheometer). Nanoindentation results of E' showed profound guardiancy of mechanical properties through the thickness, i.e. 25% change at the beginning and 6% change at the end of the stripe, and through the length of the stripe, i.e. 40% change on top layer and 60% change on the bottom layer of the stripe. Moreover, simulation of manufacturing process shows occurrence of relaxation process during unrolling, where internal stresses drops for 60% within 1000 seconds causing increase of stripe length for 0,17% within the same timeframe after stress release during cut (creep process). Results suggest that material after processing/storing and during the process of manufacturing encoders is not brought to thermodynamic equilibrium, which results in significant errors in sensor systems. However additional experiments showed that by appropriate annealing procedure these discrepancies can be reduced for 500%.

Symposium PS

Polyelectrolites, Self Assembling Fluids & Gels

Organizers: Dganit Danino, Vincenzo Guida and Laurence Ramos

Thursday 9:30 Nettuno 4

PS5

Linking extensional deformation of hagfish mucin hydrogels to their environment and dynamic structure

Katerina Rementzi¹, Lukas J. Böni², Peter Fischer³, and Dimitris Vlassopoulos⁴

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Hydrogels represent one of the most ubiquitous class of supramolecular networks which have important applications ranging from food technology to biology. Survival reasons of animals (such as hagfish) lead to a particular defense mechanism against predators. A mucin-based physical super-hydrogel is formed in few milliseconds and entraps vast amount of water. An outstanding challenge is to explore the molecular origin of slime formation, the role of the environment (natural or altered conditions) and consequently its strength. Extensional rheology of mucins were performed at different conditions by varying mucin concentrations and salt type and concentration. On the other hand, the dynamic structure of the hydrogels was investigated by means of linear viscoelasticity and dynamic light scattering. Our approach provides a simple protocol for the determination of the optimal conditions for stiffness, as defined by the longest filament breaking time and its relationship with the ionic strength. These molecular characteristics of hydrogels constitute a pathway for understanding the nonlinear rheology and, in a more general sense, the spatiotemporal techniques used allow to tune the mechanical response of polyelectrolytes such as mucus systems.

Thursday 9:50 Nettuno 4

PS6

Viscoplastic materials based on surfactant-activated microgels

Sarah Goujard¹, Jean-Marc Suau², Clémentine Locatelli-Champagne², and Michel Cloitre¹

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Modern formulations contain various ingredients including active substances - particles, emulsion droplets, perfume - and textural agents that confer the desired rheology to final products. For personal-care applications, formulations have to meet numerous requirements to satisfy both customers and manufacturers: optical transparency, innocuity, environmental-friendliness. A critical property concerns the shelf-life stability of formulations against creaming or settling with time. This requires the presence of small amounts of additives which confer viscoplastic properties to the formulations thus preventing sedimentation or creaming at rest while allowing flow during the application. Most anti-settling agents used so far are polyelectrolyte networks that swell at high pH. They are costless, extremely efficient, and wide-spread but exhibit important limitations when used in complex formulations. This prompts the development of new soft materials with tunable viscoplastic properties. Herein we describe a new approach which uses functional and structured polymeric micro-networks, which swell upon the addition of surfactants. A great challenge is to control and model

the origin of swelling and the rheology in terms of the specific interactions that develop between the polymeric micro-network and surfactant molecules. Materials properties are successfully characterized using local scale techniques like dynamic light scattering, fluorescence, microscopy, and macroscopic rheology. We investigate different families of surfactants varying at will the structure of the polymeric networks to demonstrate the versatility of the technique. We compare the rheological response of microgels activated by pH with the ones activated by surfactants and link it to their respective swelling. We will discuss new routes to increase the rheology of these materials.

Thursday 10:10 Nettuno 4

PS7

Power law viscoelasticity of a fractal colloidal gel

Stefano Aime¹, Eric Bertin², Kirsten Martens³, Luca Cipelletti¹, and Laurence Ramos¹

¹CNRS & Université de Montpellier, Laboratoire Charles Coulomb, Montpellier, France; ²Laboratoire Interdisciplinaire de Physique UMR 5588, Centre National de la Recherche Scientifique, Saint Martin d'Hères, France; ³Laboratoire Interdisciplinaire de Physique UMR 5588, Centre National de la Recherche Scientifique, Saint Martin d'Hères, France

Power law rheology is of widespread occurrence in complex materials that are characterized by the presence of a very broad range of microstructural length and time scales. Although phenomenological models are able to reproduce the observed rheological features, in general a well-established connection with the microscopic origin of this mechanical behavior is still missing. As a model system, this work focuses on a fractal colloidal gel. We thoroughly characterize the linear power-law rheology of the samples as it ages after gelation. We show that the gel linear viscoelasticity is very accurately described by the Fractional Maxwell (FM) model. Thanks to a unique set-up that couples small-angle static and dynamic light scattering to rheological measurements, we demonstrate that the powerlaw rheology originates from reversible non-affine rearrangements that take place in the gel as it is sheared in the linear regime. We discuss the possible relationship between the FM model and the microscopic structure of the gel. In order to disclose the interplay between microscopic dynamics and mechanical properties of the gel, we have developed a numerical model, based on modifications of the fiber bundle model. Our model is able to reproduce both the linear power-law rheology and the nonlinear rheology of the gel, which we probe by submitting the gel to a large number of cyclic perturbations of increasing amplitudes.

Thursday 10:30 Nettuno 4

PS8

Precursors to failure in a gel forming system

Raffaella Cabriolu¹, Mehdi Bouzid², Yassine M. Nagazy³, Kirsten Martens⁴, Emanuela Del Gado⁵, and Luca Cipelletti³

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Detecting precursors of failure in gels is an inter-disciplinary topic with important applications in numerous fields such as medical, pharmaceutical, food and cosmetic industry. Interestingly, gels behave in a viscoelastic way, flowing like viscous liquids or deforming like a solid according to the forces applied. Furthermore, gels can be fragile and local rearrangements may trigger catastrophic macroscopic failure. In addition, the study of creep dynamics in gels provides an ideal benchmark to understand how mechanical stress and failure impacts the flow properties of amorphous condensed matter. However, despite the importance of the topic, little is known on the local creep dynamics [1, 2] before the occurrence of such catastrophic events [3]. To study creep and failure at an atomic/molecular level and at time scales that are not easily accessible by experiments we chose to carry out microscopic simulations. In this work we present the response of a gel model [4], a dilute system to uniaxial tensile strain applied at different environmental conditions and we compare our results to experimental works [5] by the group of L. Cipelletti at Montpellier University.

[1] Schurtenberger, P. et al. (1991). The Journal of Physical Chemistry, 95(11), 4173-4176. [2] Leocmach, M. e al. (2014). Physical review letters, 113(3), 038303. [3] Chaudhuri, P., & Horbach, J. (2013). Physical Review E, 88(4), 040301. [4] Colombo, J., & Del Gado, E. (2014). Journal of rheology, 58(5), 1089-1116. [5] Knowlton, E. D. et al. (2014). Soft Matter, 10(36), 6931-6940.

Thursday 11:20 Nettuno 4

PS9

Microstructure of hectorite clay gels with long ageing timescale

Yee-Kwong Leong, Mingyong Du, JIshan Liu, and Pek-Ing Au

Chemical Engineering, The University of Western Australia, Perth, Western Australia 6009, Australia

Both natural and synthetic hectorite suspensions were found to display significant time-dependent or ageing rheological behaviour. The ageing behaviour was characterised by an increasing yield stress with rest time. The time scale of the ageing process was very long lasting weeks if not month. The yield stress continued to increase even after more than a week of rest. The very open honeycomb microstructure formed by these gels captured by Cryo-SEM imagery was able to explain this very long time scale. This structure was formed by strong attractive and repulsive forces. A slight displacement of particles in the network will induce force imbalance in the (whole) structure. Other particles will have to move (slightly) in response. As a result of the high number concentration of particles responding to this imbalance and navigating under the strong repulsive and attractive forces operating simultaneously, a very long time is required to achieve equilibrium. The ageing behaviour and microstructure formed by the natural and synthetic hectorite gels were found to be similar. Despite the synthetic hectorite primary particles being disk-shape with diameter of only 30 nm, the particles forming the microstructure will much larger suggesting the overlapping coin stacking structure was responsible.

Thursday 11:40 Nettuno 4

PS10

Structural, macro- and micro-mechanical properties of supramolecular bi-component L-Lysine-sodium tetraphenyl borate based hydrogels

Claude Oelschlaeger¹, Norbert Willenbacher¹, Umair Ahmed Khan², and Imran Ali Hashmi²

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We present a new class of bi-component hydrogels formed of L-lysine hydrochloride mixed with sodium tetraphenyl borate with unusual viscoelastic properties. Bulk rheological and mechanical properties have been characterized using steady and oscillatory shear rheometry as well as uniaxial compression tests. Microstructural information has been deduced from multi particle tracking (MPT) microrheology and cryo-preparation scanning electron microscopy (SEM). These gels are shear thickening at low concentrations and shear thinning at higher gelator concentration. Shear and Young's modulus data obtained from different techniques agree fairly well. Zero shear viscosity as well as modulus data obtained for gels with equimolar lysine and borate concentration exhibit concentration dependence $\eta_0 \sim c^{5 \pm 0.5}$ and $G_0 \sim c^{3.4 \pm 0.35}$, respectively. The scaling exponent for η_0 agrees well with predictions for neutral polymer in theta solvent or wormlike micelles in the slow breaking regime whereas the variation in G_0 is unexpectedly high. We attribute this to the unique microstructure comprising thin lamellae connected by tiny fibers. At low concentrations the mesh size of this structure is about 10 μm and fiber diameter increases from ~ 200 nm to ~ 2 μm , only at the highest gelator concentration of 7 wt.% the mesh size shrinks to ~ 5 μm and the fiber diameter to ~ 400 nm. Consistently, tracer particles in low concentrated gels diffuse freely in an aqueous environment. At higher gelator concentration, however, gelation takes place so fast that tracers are trapped in the elastic lamellar/fibrous regions and the modulus G'_{MPT} agrees fairly well with bulk data. Varying the molar ratio of both gel-forming components results in a pronounced viscosity maximum at fixed total gelator concentration. Corresponding microstructural changes could again be visualized using cryo-SEM consistent with MPT data.

Thursday 12:00 Nettuno 4

PS11

Dynamics of alginate/ceramic suspension droplets impacting a bath of calcium ions

Julie Godefroid¹, David Bouttes², and Cecile Monteux¹

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Dripping alginate solutions into a bath of calcium ions is a robust process that enables to obtain gelified capsules which can be used in various applications. This process relies on the fact that calcium ions bridge the alginate chains of the droplets to form a rigid gel. The Reynolds and Weber numbers, defining the competition between inertia, viscous dissipation and surface tension forces are known to influence the final shape of the droplets. Indeed inertia tends to drive the spreading of droplets upon impact with the bath while high droplet viscosity and surface tension tend to limit their extension upon impact. However, very little is known about the time evolution of the droplets shape during impact and how they relax during their fall into the calcium bath. Using a high speed camera, we study the shape of alginate/ceramic suspensions as they impact and penetrate a bath of calcium ions. We observe that droplets extend as they impact the surface and that they relax to a more spherical shape inside the bath. As expected, the drops maximum elongation increases with increasing impact velocity and decreasing droplet viscosity. The effect of the calcium concentration in the bath is less intuitive. As it increases, the maximum extension of droplets tends to decrease and the droplets tend to relax faster to a spherical shape. We perform simulations to calculate the evolution of the gelified layer as a function of time and calcium concentration through a diffusion/reaction process. We find that the droplets relaxation in the bath stops for a critical thickness of the gelled layer. We show that this relaxation is related to a syneresis phenomenon which instantaneously occurs as the droplets hit the bath: the gelled membrane tends to shrink by expelling water. This phenomenon puts the outer membrane under tensile stress and therefore is the driving force of the bead relaxation.

Thursday 12:20 Nettuno 4

PS12

Elongational flow behavior of low concentrated surfactant solutions

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Self-assembling surfactants that form wormlike micelles (WLM) are widely used as fracture fluids in enhanced oil recovery applications, which often involve complex flows with strong shear and extensional components. We investigate shear thickening WLM solutions with the aim to shed light on the flow behavior and flow-induced structure formation that develop in such complex flow fields. We employ a combination of classical rotational shear rheometry, uniaxial extension through capillary breakup elongational rheometry (CaBER), and planar elongation of the solutions using an optimized-shape cross-slot extensional rheometer (OSCER). The aqueous mixture of cetyltrimethylammonium bromide (CTAB) and sodium salicylate (NaSal) at low surfactant concentration and small salt/surfactant ratios R are employed in the study. In steady shear, the fluids exhibit a pseudo-Newtonian regime at low shear rates, with a zero shear viscosity close to that of water, followed by a sudden increase of the viscosity by about one order of magnitude, indicating shear-induced structure buildup (SIS). During filament thinning in CaBER, long filament lifetimes are observed, indicating the formation of elongation-induced structures (EIS). Particle image velocimetry (PIV) on horizontally stretched surfactant filaments reveals a heterogeneous velocity distribution, with flow in both axial directions in the filament cross-section. We further perform PIV and flow induced birefringence (FIB) measurements in planar elongation using a microfluidic OSCER in an effort to understand the underlying mechanism of EIS formation. Flow velocimetry displays Newtonian-like steady flow behavior for small elongation rates. Increasing the elongation rate leads to a time-dependent transition from a Newtonian-like to an asymmetric flow. Preliminary FIB imaging shows the development of a localized birefringent strand for intermediate rates, which oscillates laterally with increasing flow rates, similarly to the spatio-temporal fluctuations of the asymmetric flow field.

Thursday 12:40 Nettuno 4

PS13

Control of surfactant solution rheology using medium-chain cosurfactantsNikolai Denkov, Zlatina Mitrinova, and Slavka Tcholakova*Department of Chemical and Pharmaceutical Engineering, Sofia University, Sofia 1164, Bulgaria*

The addition of cosurfactants and electrolytes is known to increase significantly the viscoelastic response of surfactant solutions, due to the formation of wormlike micelles [1-3]. We present a systematic study about the role of cosurfactant molecular structure on the rheological properties of surfactant solutions [4,5]. In the absence of cosurfactant, the chosen referent surfactant system of 10 wt % SLES+CAPB has nearly Newtonian behavior and viscosity of about 8 mPa.s. The addition of cosurfactants, even in a very low concentration (1/10 of the main surfactant) may increase the viscosity of these solutions by orders of magnitude and transform them into viscoelastic gels. A wide range of ionic and nonionic cosurfactants with different head-groups, chain-lengths, and hydrophobic tail structures (linear, branched, double bonded) was experimentally studied [5]. We revealed an optimal chain-length of 8 to 10 carbon atoms of the cosurfactant molecules which ensures the highest viscoelasticity of the surfactant solutions [4,5]. Cationic cosurfactants (alkyl-TABs) and nonionic ones with small head-group (fatty alcohols and acids) are most efficient in increasing the solution viscoelasticity. There is a hierarchy in the parameters of the cosurfactant molecules which govern this behavior - most important is the head-group charge, then the chain-length and, finally, the presence of branching and double bonds in the hydrophobic tails [5]. The observed trends are explained theoretically [5] by considering the effect of the cosurfactant molecules on the properties of the entangled wormlike micelles, formed in these solutions.

[1] Cates, M. E., & Candau, S. J. (1990). Statics and dynamics of worm-like surfactant micelles. *Journal of Physics: Condensed Matter*, 2(33), 6869. [2] Ezrahi, S. et al. (2006). *PAAdvances in colloid and interface science*, 128, 77-102. [3] Parker, A., & Fieber, W. (2013). *Soft Matter*, 9(4), 1203-1213. [4] Mitrinova, Z. et al. (2013). *Langmuir*, 29(26), 8255-8265. [5] Mitrinova, Z. et al. (2018). *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 537, 173-184.

Symposium BE**Blends, Emulsions, Foams & Interfacial Rheology**

Organizers: Ernesto Di Maio, Peter Van Puyvelde and Jan Vermant

Thursday 9:30 Nettuno 5-6

BE18

Simulation of bubble growth during the foaming processChristos Mitrias, Thijs R. Egelmeers, Nick O. Jaensson, Martien A. Hulsen, and Patrick D. Anderson*Eindhoven University of Technology, Eindhoven, The Netherlands*

Polymer foams are widely used in many different types of applications. Different material properties are of interest in each application, from energy absorption during impact events to thermal and sound insulation. All of these properties are governed by the microstructure and the properties of the material matrix. Changes in microstructure arise during the foaming process. Gas bubbles are created by physical or chemical blowing agents inside the matrix fluid which then grow, followed by solidification into a cellular morphology. The material properties are affected by many parameters during the foaming process, such as bubble size and wall thickness, which are very hard to control a-priori. We have developed a novel direct numerical simulation technique with which we are able to predict the temporal morphology of the foam. Furthermore, the resulting microstructure can be used directly in simulations of solid mechanical testing, and determine the mechanical properties of the foam. The foam is described by a representative volume element (RVE), where a small number of bubbles is randomly distributed. Using this approach, the RVE can describe the bulk behaviour of the foam, while remaining computationally tractable. The matrix fluid is assumed to be Newtonian and incompressible, while inertia is neglected. Growth rate of the bubbles is enforced, by applying an internal pressure on the bubble interface. The resulting equations are discretized in space using the finite element method. To be able to accurately predict the flow in the thin layers between the bubble interfaces, an adaptive multilevel refinement technique is used. After the desired volume fraction has been reached, the mesh can be used directly as a representative volume element in solid mechanics simulations. We will present direct numerical simulations of the foaming process that allow us to predict the microstructure of the foam and thus control the material properties of the final product.

Thursday 9:50 Nettuno 5-6

BE19

Strain-softening of polystyrene-block-poly(4-vinylpyridine) diblock copolymers in melt elongation for foam processingTarek Kollmetz, Prokopios Georgopoulos, and Ulrich A. Handge*Institute of Polymer Research, Helmholtz-Zentrum Geesthacht, Geesthacht 21502, Germany*

Tailoring polymer foams requires a profound understanding of the processing properties of polymers. During expansion of foam cells, a biaxial elongational flow exists in the polymer phase. Whereas strain-hardening of polymers in elongation favours the preparation of closed-cell foams, strain-softening in elongational flows can lead to pronounced rupture of cell walls and to open-celled polymer foams. In this study, we analyse the properties of polystyrene-block-poly(4-vinylpyridine) (PS-b-P4VP) diblock copolymers in melt elongation and elucidate their potential for preparation of open-celled polymer foams [1]. In particular, the influence of the type of microphase-separated morphology on the elongational viscosity is discussed. Three PS-b-P4VP diblock copolymers with similar molecular weight, but different PS/P4VP ratios (i.e. 89/11, 76/24, 49/51) were prepared using anionic polymerization. These diblock copolymers were associated with different types of morphology (spherical, cylindrical and lamellar). Linear viscoelastic shear oscillations and stress-growth experiments in shear and elongation with a constant strain rate were performed. In the linear regime, composition (superposition of moduli) and interfacial effects caused by microphase separation (low-

frequency shoulder, plateau and regime with slope 1/2 for dynamic moduli) appear. The transient shear and extensional viscosities agree with a value of three for the Trouton ratio. In case of a cylindrical and a lamellar morphology, a pronounced strain-softening behaviour appears. For a high weight fraction of the majority phase and a spherical morphology, respectively, strain-softening is observed to a lesser extent. Consequently, strain-softening of diblock copolymer melts can be tuned by the weight/volume ratio of the two blocks. Our data clearly reveal that microphase-separated diblock copolymers are characterised by strain-softening in melt elongation.

[1] Kollmetz, T. et al. (2017). *Polymer*, 129, 68-82.

Thursday 10:10 Nettuno 5-6

BE20

Linear and non-linear mechanical properties of solid closed and open cell foams

Philippe Martinoty¹ and Antoni Sanchez-Ferrer²

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Unlike the non-linear response regime of elastomeric foams, their linear response regime has practically never been studied, although it brings key results about the structure and behavior of these foams. In this communication, we present a study of the complex shear modulus G^* and the complex elastic modulus E^* performed on foams of different nature and structure. The studied foams are 1) closed cell foams - a natural rubber (NR) foam with 100-200 μm cell size, and a polyvinyl chloride (PVC) foam with 200-300 μm cell size -, and 2) open cell foams - an ethylene propylene diene monomer rubber (EDPM) foam with 1-2 mm cell size, and a polyurethane (PU) foam with 700-800 μm cell size. These foams have been characterized by DSC, FTIR and X-ray diffraction. The measurements were carried out in a large frequency range (from ~ 0.1 Hz to $\sim 10^3$ Hz) and in the linear response regime (stress/strain ratio smaller than 10^{-4}), with piezoelectric rheometers working either in the shear mode or in the compression mode. The following question will be tackled: a) the frequency regime: hydrodynamic (NR, EDPM and PU foams) and viscoelastic (PVC foam) behavior; b) the nature of the elasticity: non-Gaussian behavior as a result of the stretching of the chains during the foam production (NR and EDPM foams); c) the influence of a static uniaxial compression applied on foams during the shear or the compression measurements (the existence of two regimes which correspond to the compression of air contained in the cells when the static compression applied to the foams is smaller than 30%, followed by a sticking of the polymer membranes forming the faces of the cells. In contrast, the open cell PU foam shows a progressive decrease of E , which saturates to a value consistent with that of the genitor system). Stress-strain experiments were also performed by submitting these foams to uniaxial elongations and compressions and discussed in conjunction with the linear results.

Thursday 10:30 Nettuno 5-6

BE21

Rheological properties of biosourced foams produced by microchannels at high throughput

Julian R. Sepulveda¹, Dominique DellaValle², Catherine Loisel², Alain Riaublanc³, and Agnès Montillet¹

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Aqueous foams have been described as viscoplastic fluids whose interesting properties stem from their two-phase structure. This aerated structure is highly appreciated since it imparts some desirable characteristics like smoothness and lightness to foods. The traditional processes for food foam production usually present some drawbacks such as high energetic cost or heterogeneity of bubble sizes. Recently, the use of microchannels has emerged as an interesting alternative to produce emulsions and foams with uniform and controlled size distribution of bubbles and droplets. The use of this technology is becoming increasingly important due to cheaper manufacturing and operating cost, higher heat and mass transfer performance and enhanced mixing. The aim of this research project is to produce stable, structure-tailored foams in agreement with the food industry. The innovative component of this research is the production of foam at high throughputs using a continuous system based on the arrangements of microchannels. The microchannels were integrated to a new experimental setup designed to gain new insights into the phenomena taking place at this scale. For the elaboration of foam, model solutions are prepared from whey protein isolates at 3% (w/w) and xanthan gum at different concentrations (0.2, 0.4% w/w). The foaming stage is carried out using microchannels of varied geometrical configurations. The effect of the different configurations on the foam rheological properties is evaluated from a classical experimental approach. The elastic modules of the foams are characterized in the linear viscoelastic domain. The Herschel-Bulkley model is applied for the experimental description of the viscosity profiles. Some differences have been found at certain flowrates for the different microchannel configurations. Additionally, an attempt is being made to theoretically model the foam viscosity at the process scale by a Krieger-Dougherty modified model applicable to the case of foams.

Thursday 11:20 Nettuno 5-6

Keynote BE22

Use of rheology to determine water fluxes and encapsulation efficiency in double emulsions

Véronique Schmitt¹ and Maxime Nollet²

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We use rheology to study the influence of the emulsification process on encapsulation efficiency of drugs in double water-in-oil-in-water emulsions [1]. Two drugs are considered, first vitamin B12 which can be considered as a model drug and secondly a suspension of *Cydia pomonella* Granulovirus (CpGV), a virus used in organic agriculture to protect fruits against the Carpocapse insect. Encapsulation is measured by classical UV-Vis spectroscopy method. Additionally we show that rheology is a useful tool to determine water exchanges during emulsification. In a two-step emulsification process, using rotor-stator mixers, encapsulation reaches high levels, close to 100% whatever the flowing regime. This encapsulation decreases only if two conditions are fulfilled simultaneously: (i) during the second emulsification step the flow is turbulent and (ii) it leads to excessive fragmentation inducing formation of too small drops. We also investigate the effect of a deliberate loss of osmotic pressure balance on the encapsulation and characterize the induced water fluxes. We show that encapsulation of vitamin B12 is not affected by the osmotic pressure unbalance,

while water exchanges, if they exist, are very fast and aim at restoring equilibrium. As a consequence, the emulsification efficiency is not very sensitive to osmotic stresses provided that the interfaces resist mechanically. In a similar way, rheology can also be used to assess the double emulsion stability under storage. We determine the effect of free lipophilic stabilizer in the intermediate phase and the inner droplet volume fraction and plotted the results in a stability diagram. We show that by a judicious choice of the composition, double emulsion may act as efficient capsules over a large period of storage.

[1] Nollet, M. et al. (2016). *Soft matter*, 12(14), 3412-3424.

Thursday 12:00 Nettuno 5-6

BE23

Rheology and structure of drying emulsions

Marie Goavec¹, Vincent Gaudefroy², Stéphane Rodts¹, and Philippe Coussot¹

¹Laboratoire Navier, Université Paris-Est, Champs-sur-Marne, France; ²MAST MIT, IFSTTAR, Nantes, France

Direct (water-in-oil) emulsions are used in various fields, in particular for their ability to dry and finally form uniform liquid or solid surfaces: cosmetics, paints, paving industry (bitumen emulsions), foodstuffs (spray-drying). In these applications the emulsion films used are thin, which makes direct observations difficult. In order to get a deeper insight in the evolution of the microstructure and rheological properties of drying emulsions we here focus on thick (centimetric) emulsion layers. We look at the local properties of these materials with the help of MRI (Magnetic Resonance Imaging): more specifically, we image water and oil separately to obtain their spatial distribution inside the drying emulsion. We also follow the evolution of the rheological properties of the emulsion layer with the help of a specific set-up allowing drying in a rheometer. It appears that a slight water concentration gradient forms within the emulsion, while an oil layer develops at the surface, which explains the strong decrease of the drying rate in time. Our measurements show that the rheological behavior of the emulsion layer below this liquid film is similar to that of an emulsion directly prepared at the same average concentration. Neither the initial emulsion composition nor the drying airflow speed affect the concentration distribution and the material strength evolution. Indeed, the elastic modulus of the emulsions studied follow a master curve, indicating that a drying emulsion fundamentally behaves like an emulsion that is progressively concentrated in oil. Confocal microscopy observations of the emulsion structure in time show that during this concentration coalescence is minor, until the concentration reaches a critical value, in agreement with the above results. Ultimately, the insight provided by this work allows the establishment of a comprehensive drying model for emulsions.

Thursday 12:20 Nettuno 5-6

BE24

Flow-induced nanostructuring of gelled emulsions: a small-angle neutron scattering study

Luigi Paduano¹, Stefano Guido², Antonio Perazzo³, and Valentina Preziosi³

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In this work, we present a small angle neutron scattering investigation on emulsions system that at rest exhibit a microstructure made of an oil-swollen water phase dispersed in an oil phase. In particular, the system is constituted by two common nonionic surfactants in a range of water concentration where complex and diverse microstructures are found at rest, such as multilamellar and bicontinuous phases. By increasing water concentration, a quite stable bicontinuous gelled microstructure is formed at rest, but even in this case the emulsion evolves into a concentrated suspension of droplets once a shear flow is applied. The microstructure of the system has been studied by Rheo-VSANS (very small angle neutron scattering under shear flow) in with a shear rates ranging from 0 to 500 s⁻¹. The scattering profile $I(q)$ evolves to a shear-rate dependent plateau at low q -values. This allows determining the radius of gyration of the scattering aggregates through the Guinier equation. The size of the scattering objects increases at low shear rates from 800 up to 1000 nm, while a further increase of the shear rates lead to a drastic decrease of the size of the aggregates. The results support a droplet-based microstructure of the system with a symmetric shape of the aggregates. The result of the present work elucidates how flow affects the microstructure of multicomponent emulsion systems and is relevant for industrial applications.

Thursday 12:40 Nettuno 5-6

BE25

Monitoring complex fluids microstructure by using organic electrochemical transistors

Mario Barra¹, Valentina Preziosi², Antonio Perazzo³, Giuseppe Tarabella⁴, Paquale D'Angelo⁴, Salvatore Iannotta⁴, Antonio Cassinese¹, and Stefano Guido²

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Organic electrochemical transistors (OECTs) are amplifying transducers of chemical and biological signals. In an OECT, a poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) channel connects two electrodes (source and drain) and is in contact with an electrolytic medium. The device is completed by a third electrode (gate) which is directly immersed in the electrolyte solution. When a positive voltage (VGS) is applied between the gate and source, the positively charged species contained in the electrolyte are pushed away from the gate electrode and are injected into the PEDOT:PSS backbone, neutralizing the PSS- sites and de-doping the active channel. Hence, this device allows to convert and amplify small variations of the ionic currents (~IGS, which is the gate-source current) flowing through the electrolyte into changes of the electronic IDS current. In this work, first of all, we demonstrate that OECTs based on PEDOT:PSS active channels can be used to reveal the presence of worm-like micelles in surfactant-salt aqueous solutions. In the worm-like regime, indeed, the response of these devices differs distinctively from that exhibited when pure surfactant solutions, containing only spherical micelles, are analyzed [1]. Then, we report how OECTs can also be exploited to detect microstructural features of oil/water emulsions [2]. To this purpose, the response of OECTs is investigated for samples obtained at different stages of a nanoemulsification process carried out by gradually adding water to a mixture of oil and two non-ionic surfactants. We relate the OECT behavior to the clustering and percolation of water droplets as detected by confocal

laser scanning microscopy and rheometrical measurements. As a whole, the results here discussed can lay the foundation for the quantitative application of OECTs to identify the microstructure in surfactant-based complex fluids.

[1] Preziosi, V. et al. (2015). RSC Advances, 5(21), 16554-16561. [2] Preziosi, V. et al. (2017). Journal of Materials Chemistry C, 5(8), 2056-2065.

Thursday Afternoon

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Thursday 14:30 Sirene

CS27

The interaction of spherical particles in simple-shear flows of yield stress fluids

Mohammadhossein Firouznia¹, Bloen Metzger², Guillaume Ovarlez³, and Sarah Hormozi¹

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The interaction of two particles in shear flow is of central importance in understanding the microstructure of suspensions. We study the interaction of two neutrally buoyant spheres in linear flow fields of Newtonian, yield stress and shear thinning fluids. A series of experiments have been performed over a range of shear rates as well as different shear histories using a planar Couette apparatus and with the aid of rheometry, Particle Image Velocimetry, and Particle Tracking Velocimetry. The non-Newtonian nature of the suspending fluid strongly affects the shape of the trajectory map of particles and the irreversibility. Depending on the shear rate, nonideal yield stress and shear thinning suspending fluids might exhibit elasticity that needs to be taken into account. The disturbance field around one particle is studied in different fluids when subjected to shear. Using these results to explain the two particle interactions, we show how contact and non-Newtonian behaviors result in fore-aft asymmetry in particle trajectories. Finally, we discuss how the bulk rheology and the underlying microstructure are affected by particle trajectories in complex suspensions.

Thursday 14:50 Sirene

CS28

Rheology and electric field response of fumed nanoparticles in nematic liquid crystal suspensions

Saket Kumar and Prachi Thareja

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In this work, we investigate the rheology and response to the applied electric field (E) of fumed Al₂O₃ nanoparticles in the nematic liquid crystal (NLC), N-(4-Methoxybenzylidene)-4-butylaniline (MBBA) suspensions. The inclusion of fumed Al₂O₃ nanoparticles (NPs) in MBBA NLC results in a sol-gel transition at a NP volume fraction $\Phi=0.014$ and the formation of self-supporting solid-like suspensions on further increasing the NP Φ . The frequency sweep response of the fumed Al₂O₃/MBBA suspensions at and above NP $\Phi=0.014$ is explained using the soft glassy rheology (SGR) model, indicative of the existence of the glassy dynamics. Our results show that when the suspensions are sheared progressively, the storage modulus (G') increases at shear rates above 500 s⁻¹. We hypothesize this increase in G' is due to the shear-induced network formation of smaller sized flocs of fumed Al₂O₃ NP. The DSC scans of the suspensions indicate that on increasing the fumed Al₂O₃ NP Φ to 0.007 and 0.030, the isotropic-nematic transition temperature (TNI) decreases relative to the particle free MBBA NLC, accompanied by the broadening of the transition peak at a NP $\Phi=0.014$ and 0.030. At a NP Φ of 0.007, optical microscopy of the fumed Al₂O₃/MBBA suspensions shows that on decreasing the temperature below the TNI of MBBA, the NLC domains grow and get confined in the pre-existing network of Al₂O₃ NP flocs. We further demonstrate the suspensions having NP Φ at and above 0.007 undergo E driven reversible nematic-isotropic phase transition. The time required for transition reduces on increasing the NP Φ and/or the magnitude of E. In summary, addition of fumed Al₂O₃ NP in MBBA NLC is a viable way of introducing disorder in the NLC and subsequently, the rheology of the suspensions can be easily tuned by varying the fumed Al₂O₃ NP Φ . We also show that the suspensions can exhibit an E driven phase transitions.

Thursday 15:10 Sirene

CS29

Rheology and Microstructure of Colloidal Suspensions in Confined Flows

Joao Maia¹, Shaghayegh Khani¹, and Arman Boromand²

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Bridging the gap between the micro-structure and rheology, we have investigated the effect of confinement on the shear-thickening behavior of soft to rigid colloidal suspensions. Shear-thickening phenomenon and its physical origin have been the subject of numerous experimental and theoretical studies. In a recent numerical study by our group, the role of hydrodynamic lubrication and frictional interactions in rheological response of dense and semi-dense colloidal suspensions has been explored. We could successfully replicate the whole range of continuous and discontinuous shear thickening regime. Formation of a frictional percolating network at high shear stresses was found to be the origin of discontinuous shear thickening behavior. On the other hand, hydro-clusters formed at low stresses that bring particles together and nucleate the frictional network are responsible for the continuous shear thickening behavior of such complex fluids. The observed microstructural and rheological changes of the colloidal suspension are indeed dictated by the interplay between the hydrodynamic and frictional interactions. Particle-Particle elastic interactions significantly influences the flow behavior and microstructure of such systems. It is expected that this effect will be enhanced in confined geometries. Thus, in this work we report on the rheological behavior and microstructure development of soft to rigid colloidal suspensions in Pouseille flow in mildly and strongly confined geometries, and how they are changed from unconfined conditions.

Thursday 15:30 Sirene

CS30

Interfacial slip of colloidal suspensions investigated by near-wall dynamic light scatteringAntonio Giuliani, Benoit Loppinet, and Ruel McKenzie*FORTH-Institute of Electronic Structure and Laser, Heraklion, Greece*

The appearance of slip on colloidal suspension is a long standing issue, relevant to a large number of processes. Flow boundary conditions ($v(z=0, \text{gap})$) are difficult to verify and of similar rheological signature to other flow instabilities. We present results of in situ dynamic light scattering velocimetry for measuring near wall velocimetry and slip. The technique uses an evanescent wave that penetrates sub-micron levels and enables the capability of tracer free monitoring (for colloidal suspensions). This relatively simple method is implemented on stress-controlled commercial rheometers on continuous flow and LAOS. We probed a broad range of suspensions; here we report evidence of slip ranging from weak slip in polymer solutions to full slip in weak gels.

Thursday 16:20 Sirene

CS31

Rheology of a suspension of colloidal plate-like particles with repulsive electrostatic interactionsVincent Labalette¹, Alexis Praga¹, Florent Girard¹, Yannick Hallez¹, Martine Meireles¹, and Jeffrey Morris²¹*Laboratoire de Génie Chimique, Université de Toulouse, Toulouse 31062, France;* ²*Department of Chemical Engineering, CUNY City College of NY, The Benjamin Levich Institute, New York, NY, United States*

The shear rheology and microstructure of a suspension of charged, plate-like, particles are studied numerically. Hydrodynamic and electrostatic interactions are considered at the particle scale to better understand the local force balances driving the macroscopic behavior of the suspension. In order to simulate plate-like particles, hard spheres are bound together using five virtual springs per pair of particles, which maintains nearly rigid body motion of the plate-like aggregate. The hydrodynamic response of an ellipsoid coarse-grained with this method is studied with the Accelerated Stokesian Dynamic (ASD) method and the results are compared with the Jeffery's orbits theory. Electrostatic interactions are included classically between the spheres constituting the aggregate by a pairwise additive Yukawa potential. Detailed computations of the electrostatic interactions between sphere aggregates reveal that electrostatic forces approximated in such a way are underestimated by ~20%. This error comes from a multi-body effect (distortion of the electronic clouds) and is comparable to the uncertainty of the hydrodynamic interactions. The microstructure and stresses developed in a colloidal suspension of plate-like colloids are studied as a function of the Péclet number and of the electrostatic interaction strength and range.

Thursday 16:40 Sirene

CS32

Polydispersity influences on the shear thinning behavior of rodlike colloidsChristian Lang¹ and P. Lettinga²¹*ICS-3, Soft Matter, Forschungszentrum Jülich, Jülich, NRW 52428, Germany;* ²*Laboratory for Soft Matter and Biophysics, University of Leuven, Leuven, Belgium*

High aspect-ratio colloidal particles are becoming increasingly more important components in a wide range of technologies and products. In biology, they constitute the frame of the cytoskeleton in form of F-actin and micro tubular networks and amyloids are responsible for a large number of diseases such as Alzheimer disease. The mechanical properties of complex fluids containing such rod-like colloids are hugely affected by flow via the particle orientation. The morphology of rods, thereby, plays a key role in the microscopic behavior which leads to the macroscopic rheological response. In biological as well as industrial samples, additionally, polydispersity of rods complicates the observable flow behaviour. We investigate the rheological response of bidisperse rod suspensions in the semidilute concentration regime by mixing two well-defined rodlike species, namely the pf1 and the fd virus. This enables us to assess theoretical predictions and define mixing rules for the zero shear viscosity as well as the nonlinear shear viscosity. We determine the zero shear viscosity as a function of relative volume fraction and compare this to the theoretical prediction. It is found that the underlying rotational diffusion leading to the zero shear viscosity is strongly reduced in comparison to the free diffusion of a single rod. In presence of a species with different molecular weight, the zero shear viscosity of a species remains unaffected. The mixing rule underlying nonlinear shear behaviour of a bidisperse rodlike polymer suspension is surprisingly almost linear. This points to the fact that shear induced tube dilation is playing an important role for the nonequilibrium behavior of rods under shear flow. Again, the effect of a secondary species on the nonequilibrium shear thinning behaviour of the primary species seems to play a minor role.

Thursday 17:00 Sirene

CS33

Magnetic nano-colloids in viscoelastic media: magnetic susceptibility, nanorheology and magnetoviscous effectA. E. A. S. Evangelopoulos and Patrick Ilg*Mathematics & Statistics, University of Reading, Reading, United Kingdom*

Magnetic colloids in the range of around 10 nanometers have found several engineering applications but are also increasingly used in biomedical treatments such as e.g. hyperthermia and magnetic drug targeting or as a diagnostic tool [1]. Rheological properties of magnetic nanoparticles in Newtonian solvents (so called 'ferrofluids') are rather well understood to date [2]. In biomedical applications, however, the colloidal particles experience an environment that is more complicated than a Newtonian liquid. As a first step and generalising previous work [3], we here model the dynamics of magnetic nanoparticles in a combined Newtonian and viscoelastic (Maxwell) solvent. In the dilute limit, we find analytically the modifications of the Debye susceptibility due to the viscoelastic contributions. Our results show the failure of the Bishop-di Marzio approach with important consequences for using magnetic susceptibility measurements as nanorheological probes [4]. Finally, we consider the change of apparent viscosity due to an externally applied magnetic field, the so-called magnetoviscous effect. From computer simulations and approximate analytical calculations, we work out the influence of the viscoelastic environment on the magnetoviscous effect. Overall, we find that the

relative viscosity increase due to hindered rotations of the nanoparticles becomes less pronounced with increasing viscoelasticity [5].

[1] Colombo, M. et al. (2012). Chemical Society Reviews, 41(11), 4306-4334. [2] Odenbach, S. (Ed.). (2009). Colloidal magnetic fluids: basics, development and application of ferrofluids (Vol. 763). Springer. [3] Raikher, Y. L. et al. (2013). Soft Matter, 9(45), 10857-10865. [4] Roeben, E. et al. (2014). Colloid and Polymer Science, 292(8), 2013-2023. [5] A.E.A.S. Evangelopoulos, P. Ilg. In preparation (2017).

Thursday 17:20 Sirene

CS34

Role of polymer matrix architecture on the rheology and flow induced microstructure of colloidal dispersions

Roberta Massaro¹, Gabriele Colombo², Christian Clasen¹, Jan Vermant², and Peter Van Puyvelde¹

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The balance of hydrodynamic and interparticle forces determines the microstructure of colloidal dispersions and their macroscopic behavior under flow. When the suspending medium is a polymer melt, polymer-mediated forces between particles such as depletion and bridging must be taken into account. Both are attractive and lead to the formation of flocs and, eventually, to percolation and gel formation at higher concentrations. Flow can induce structural changes, which manifest in a variable viscosity that, if reversible and time dependent, leads to a thixotropic behavior of the system. The time scales associated with this structuration are typically longer than the classical viscoelastic time scales of the components but faster than other slow phenomena as ageing or degradation. In many relevant thixotropic systems, the suspending medium is viscoelastic. In that case there will be a competition between the time scale associated with the particulate network and the time scale associated with the inherent viscoelasticity of the matrix. The role of a viscoelastic medium was investigated here experimentally by studying model colloidal particles in polymeric media of different architecture. First, the initial states of the dispersions were quantified based on the high frequency rheometry to measure the effective hydrodynamic volume fraction of the aggregates. Second, a high speed rheo-confocal microscope, equipped with structured illumination optics, was used to study the structural evolution during steady state and transient flows. By using a counterrotating rheometer mounted onto the confocal the changes in microstructure as well as the rheology could be followed. In this manner the contributions to the stress of the different components in dispersions in polymeric matrices have been studied as a function of polymer matrix architecture.

Thursday 17:40 Sirene

CS35

Channel flow of a colloidal suspension

Sebastian Fritschi and Matthias Fuchs

Fachbereich Physik, Universität Konstanz, Konstanz, Germany

Pressure-driven flow through channels provides a test for spatially inhomogeneous flow in driven complex fluids as the shear rate and thus the induced local structural relaxation naturally varies across the channel. We present results from particle-based simulations on pressure-driven flow of a glass-forming suspension made up of Brownian hard disks through a rough channel in 2D. At high concentrations a central plug develops where the glassy material moves uniformly while the shear is localized to narrow regions close to the walls. We confirm a criterion for plug formation based on the dynamic yield stress present in a glass. This stationary inhomogeneous flow is accompanied by local variations of the shear-rate, pressure, density and strongly affects the structural dynamics. In yielding glassy states, normal stress and pressure correlations can be observed which point to non-local stress-strain relations. We further compare our results to hybrid-Lattice Boltzmann-Mode Coupling Theory calculations [1], which rationalize driven fluid states.

[1] Papenkort, S., & Voigtmann, T. (2015). The Journal of chemical physics, 143(20), 204502.

Symposium NF

Non Newtonian Fluid Mechanics & Flow Instabilities

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Thursday 14:30 Ulisse

NF27

Localized structures in rheologically complex fluids

Octavio Manero

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In this work, the mechanism suitable for the generation of well-defined stationary localized solutions in rheologically complex fluids is presented. The systems analyzed here can exhibit spatially homogeneous periodic oscillations corresponding to a supercritical bifurcation which generate Turing patterns or spatially extended patterns. Due to the properties of the solutions discussed here, these self-organized structures are named dissipative solitons. The stabilization of these localized structures stems from the material parameters of complex fluids, namely, fluids that exhibit flow instabilities, like shear-banding. It is shown that these parameters are close to the Turing bifurcation point in such a way that only one stable solution exists. This analysis is carried out with a model that consists in an upper-convected Maxwell-type constitutive equation coupled to an evolution equation for the structure variable, in which both diffusion of the stress and that of the structure variable are included (diffusive BMP model).

Thursday 14:50 Ulisse

NF28

Solutions of pressure-driven flows of yield stress fluids with pressure-dependent rheological parameters

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The lubrication flow of a Herschel-Bulkley fluid in long channels and tubes of varying width and radius is modeled using the approach proposed by Fusi et al. for a Bingham plastic [1]. Both the consistency index and the yield stress are assumed to be pressure-dependent. In the planar case, the one-dimensional pressure distribution is calculated numerically solving an integro-differential equation and then the position of the yield surface and the two velocity components are computed using semi-analytical expressions. In the axisymmetric case, a system of two equations needs to be solved for the pressure and the radius of the unyielded core. Some analytical solutions are also derived for channels (or tubes) of constant and linearly-varying widths (radii) and comparisons are made with known analytical solutions for Bingham Poiseuille flow. Under the lubrication approximation, the shape of the yield surface in the case of planar flow depends only on the wall function and the power-law exponent, whereas its elevation depends on all parameters. Hence, in a channel of constant width, the width of the un-yielded core is also constant, despite the pressure dependence of the yield stress, and the pressure distribution is not affected by the yield-stress function. The axisymmetric flow turns out to be more complex than expected. The implications of the pressure-dependence of the material parameters and the applicability windows of the method are also discussed.

[1] Fusi, L. et al. (2015). *Journal of Non-Newtonian Fluid Mechanics*, 221, 66-75.

Thursday 15:10 Ulisse

NF29

Simulation of the flow in fluid dampers: effects of fluid elasticity and plasticity

Alexandros Syrakos and John Tsamopoulos

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Fluid dampers are used in a variety of applications of engineering interest, dissipating mechanical energy into heat through the action of viscous stresses in a fluid, which arise by forcing the fluid to flow through a constriction. Typical damper fluids (e.g. silicone oil, magnetorheological fluids) have properties such as shear-thinning, elasticity, and in some cases plasticity. Although in most studies the damper is treated as a "black box" with only the overall response recorded and modelled, numerical simulation of the whole flow in the damper can provide a much more detailed picture. In the literature, very few studies employ such simulations and they assume the fluid to be either Newtonian or generalised Newtonian. The present study concerns numerical simulations of the flow in fluid dampers when a sinusoidal motion is imposed on the damper piston, performed with a finite volume method, modelling the fluid through the Newtonian, Carreau-Yasuda, Bingham, and Phan-Thien & Tanner constitutive equations. It is shown that, compared to available experimental studies, although the generalised Newtonian models can capture some of the characteristics of damper behaviour, in most cases it is necessary for the constitutive model to include viscoelastic effects in order to obtain a qualitatively accurate representation of the damper's behaviour. In particular, fluid elasticity is responsible for the hysteresis typically exhibited in diagrams of damper force versus piston displacement or velocity, which is referred to as damper "stiffness". Furthermore, very often in damper literature it is assumed that, because the width of the constriction is small, a complete picture of the damper operation can be obtained by assuming the flow there to be one-dimensional; however, the present results show that elasticity retards the attainment of fully developed flow as the fluid enters the constriction, and therefore the assumption of one-dimensional flow will often be invalid.

Thursday 15:30 Ulisse

NF30

Pattern formation and fingering instability in carbon black gels

Badis Marsit¹, Irmgard Bischofberger¹, and Thibaut Divoux²

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²*Civil & Environmental Engineering MIT, CNRS, Cambridge, MA 02139, United States*

We study the formation of patterns in carbon black gels, i.e. a colloidal gel composed of attractive soot particles, and whose rheology is strongly time-dependent. The gel is sandwiched between two parallel plates separated by a gap spacing H and connected to a rheometer, which allows us to tune the gel's pre-shear history. The gel is brought to rest through a decreasing ramp of shear stress. The plates are then separated at constant speed V , which leads to the formation of a broad variety of patterns on both plates, from stable cones to unstable tree-like structures, when varying the speed V and the initial gap spacing H between the plates. The transition between the stable and the unstable regime occurs for increasing velocity and decreasing gap spacing. These two parameters also define the number of branches of the tree-like patterns. Here, we will provide a complete phase diagram of the different patterns and discuss the role of the fluid rheology as well as the impact of the pre-shear history on the pattern formation.

Thursday 16:20 Ulisse

NF31

Elastic instabilities in injection molding

Mick Carrozza¹, Martien A. Hulsen¹, Tim Smit¹, Arjen Bogaerds², Pieter Janssen³, and Patrick D. Anderson¹

¹*Eindhoven University of Technology, Eindhoven, Netherlands Antilles;* ²*DSM, Geleen, The Netherlands;* ³*SABIC, Bergen op Zoom, The Netherlands*

The fountain flow instability that occurs during the filling stage of the injection molding process has been investigated numerically with the use of transient, non-linear finite element method simulations. Studying the instability, being of viscoelastic nature, is relevant for polymer processing since it potentially causes surface defects to the final product that are often called tiger stripes. It will be shown how the flow instability appears in experiments and what its effect is on end products. In an attempt to model the fountain flow, the problem is stated and the governing equations will be explained. The problem is discretized in both space and

time using finite element and finite difference methods and two different approaches for the treatment of the free surface have been taken into account that will be explained conceptually: the heightfunction approach and a 2D boundary tracking method. Eventually, results obtained with these methods are shown in which the influence of the polymer melt rheology on the instability has been investigated. The melt rheology can be coupled to material properties, which is important for the industry, and insight in the physical mechanism behind the instability can be gathered with numerical simulations like these.

Thursday 16:40 Ulisse

NF32

Wetting of Yield-Stress Fluids

Catherine Barentin¹ and Loren Jørgensen²

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Yield-stress fluids such as emulsions, polymer microgels or foams exhibit interesting mechanical properties depending on the applied stress: they behave like an elastic solid below a critical stress called "yield stress" and flow like a liquid above it. This intermediate solid/liquid behavior makes them particularly interesting for applications but fundamentally difficult to describe. In this talk, I will study the wetting properties of yield stress fluids and especially the spreading of a yield-stress-fluids droplet on a solid surface. In the case of simple fluids, this experiment is classical and the corresponding Young-Dupré wetting law is well known. Here I will study the influence of the yield stress on the final contact angle and show the strong impact of the dynamical history and of the boundary conditions. More importantly, I will show that exploring the competition between surface tension, which is an equilibrium property, and yield stress effects that often keep the system out of thermodynamical equilibrium due to a dynamical arrest is possible as soon as force balances are performed and I will extend Young Dupré law to the case of yield-stress fluids.

Thursday 17:00 Ulisse

NF33

Spreading behaviour, structures and properties of complex fluids

Christophe Kusina¹, Jean-Baptiste Boitte², Odile Aubrun², Danielle Leverage², Hamid Kellay³, and Annie Colin¹

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Complex fluids (emulsions, solid dispersions, gels) with non-Newtonian behaviours are often found in several industries (food, cosmetic) as products to be used by a consumer. Thus, performances delivered (optical, mechanical or sensorial) by the usage of the product must be studied in order to optimize their compositions. From a scientific point of view, numerous parameters have to be taken into consideration to simulate the real life spreading of a product through in vitro experiments. The spreading, due to the shear effect induced by the gesture, challenges the rheological properties of the complex fluid in dynamic conditions which causes a microstructure evolution. However, these physical-chemical phenomena and the link between structure and property during the spreading of a cosmetic product on the skin are still not well understood. For that purpose, we develop an innovative blade coating system that mimics the spreading of a product and observe the microstructure of the formed deposit and how it evolves with time. The system consists of a flexible blade which spreads a liquid on an acrylic glass plate mounted on a microscope. With this system, we study the fundamental parameters that are involved in the film formation. We found that two main conditions determine the existence of the film: first, the raising of the blade by the liquid, and the spreading of the liquid faster than the de-wetting contact line. At low velocity, the fluid is mainly slipping: the gap between the blade and the substrate is 0. At high velocity, a uniform film is produced. In the intermediate situation, a various thickness heterogeneous film is formed, driven by the quantity of product to spread and the normal force applied by the blade onto the product. The formation of the liquid film is governed by several parameters (i.e. capillary number, spreading velocity, yield stress and the elasticity of the blade). We currently investigate the effect of above parameters in order to obtain a better understanding of the spreading phenomena.

Thursday 17:20 Ulisse

NF34

Natural convection in shear-thinning fluids: velocity and temperature measurements by MRI

Christel Metivier, Sebastien Leclerc, Mohamed Darbouli, Thomas Vare, Cherif Nouar, and Dynmuhambet Baymbetov

LEMTA, Nancy, France

An experimental investigation of the Rayleigh-Bénard convection in shear-thinning fluids is presented. The experimental setup consists on a cylindrical cavity defined by a finite aspect ratio $A=D/d=6$. Both velocity and temperature fields are obtained by using MRI. In particular, we use an innovative technique to measure temperature called the Magnetic Resonance Thermometry (MRT). In our case, the temperature fields are obtained by measuring the transverse relaxation time T_2 . We have validated this technique with glycerol and we obtain a temperature resolution close to 1°C. Concerning the Rayleigh-Bénard configuration, flow structure is determined at different Ra number from the velocity and temperature mappings for a Newtonian fluid, glycerol, and for shear-thinning fluids, xanthan gum aqueous solutions with weight concentrations ranging from 0.1% to 0.2%. In the case of glycerol and xanthan solution at 0.1%, one recovers similar experimental results in terms of criticality with Ra_c close to 1800 and patterns since the convection is characterized by rolls. When the xanthan concentration is increased, the critical Rayleigh number is not modified, however the onset occurs with hexagonal pattern. Because the critical temperature differences increase with the concentrations due to an increase in viscosity, one can think that hexagonal patterns are due to variations of physical properties with temperature (non Oberbeck-Boussinesq effects). Similarities with some results obtained in the Newtonian case are highlighted. We have observed a transition from hexagonal patterns to rolls by increasing the Rayleigh number. This pattern transition is characterized by a discrepancy in the maximal velocity values. By using shear-thinning fluids, results show an increase in the intensity of convection compared with the Newtonian case. A comparison with theoretical results is also proposed.

Thursday 17:40 Ulisse

NF35

Elastic turbulence in a serpentine micro-channel: onset, development, statistics and decay properties

Antoine Soulies, Cathy Castelain, and Teodor Burghelua

Laboratoire De Thermique et Energie de Nantes, Nantes, France

The first part of the talk concerns with a systematic experimental investigation of the onset, development, and statistical and scaling properties of elastic turbulence in a curvilinear micro-channel of a dilute solution of a high molecular weight polymer is presented. By measurements of time series of high spatial resolution flow fields performed over a time 320 times longer than the average relaxation, we show that the transition to elastic turbulence occurs via an imperfect bifurcation. Slightly above the onset of the primary elastic instability, rare events manifested through a local deceleration of the flow are observed. By measurements of the spatial distributions and statistics of the second invariant of the rate of strain tensor, we show that the main prediction of the theory regarding the saturation of root mean square of fluctuations of the velocity gradients [1, 2] is qualitatively verified though a quantitative agreement could not be found. A systematic analysis of the statistics of the fluctuations of flow fields in terms of spatial and temporal correlations, power spectra, and probability distributions is presented. The scaling properties of structure functions of the increments of the velocity gradients are discussed. A systematic description of the elastic stress boundary layer is presented. The second part of the talk concerns with a systematic experimental description of the decay properties of elastic turbulence in a plane micro-channel flow. By accurate measurements of the temporal and spatial distributions of the fluctuations of the mean flow at various positions downstream the characteristic decay length is measured. The dependence of the characteristic decay length on the Weissenberg number is discussed.

[1] Balkovsky, E. e al. (2001). Physical Review E, 64(5), 056301. [2] Fouxon, A., & Lebedev, V. (2003). Physics of Fluids, 15(7), 2060-2072.

Symposium SM**Polymer Solutions & Melts**

Organizers: Yuichi Masubuchi, Angel Moreno and Daniel Read

Thursday 14:30 Tritone

SM22

Viscoelastic and dielectric relaxation of reptating type-A chains affected by head-to-head association/dissociationHiroshi Watanabe¹, Yumi Matsumiya¹, and Youngdon Kwon²

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For entangled linear polymer having type-A dipoles and undergoing reversible head-to-head association and dissociation, viscoelastic and dielectric behavior is theoretically analyzed on the basis of the reptation equation of motion combined with the association/dissociation kinetics. Specifically, for the dissociated and associated chains referred to as the unimer and dimer (indexed with $j=1$ and 2 , respectively), the normalized complex modulus $g_j^*(\omega)$ and normalized dielectric permittivity $\epsilon_j^*(\omega)$ are analytically calculated via eigenfunction expansion of orientational anisotropy and orientational memory defined in terms of the bond vectors u of entanglement segments. The anisotropy relaxation functions of the unimer and dimer exhibit multiple mode coupling due to the association/dissociation reaction, and viscoelastic $g_j^*(\omega)$ determined by this function exhibits significant mode broadening compared to the pure reptation case. In contrast, only a pair-wise mode coupling occurs for the memory relaxation functions of the unimer and dimer, so that $\epsilon_j^*(\omega)$ reflecting this function exhibits just moderate mode broadening. This difference between $g_j^*(\omega)$ and $\epsilon_j^*(\omega)$ results from a difference in the averaging moment of u : The orientational anisotropy is a tensorial, second moment average of u , whereas the orientational memory is a vectorial, first moment average. The same difference between $g_j^*(\omega)$ and $\epsilon_j^*(\omega)$ is noted also for the associating/dissociating Rouse chains, but the relaxation mode broadening is quantitatively less significant for the Rouse chains than for the reptating chains. The origin of this difference is discussed in relation to coherence of the segment motion that emerges in the reptation dynamics but not in the Rouse dynamics. Viscoelastic and dielectric data of a typical type-A polymer, cis-polyisoprene, are also presented to demonstrate this effect of motional coherence.

Thursday 14:50 Tritone

SM23

Shear and extensional rheology of entangled bulk polymers functionalized with metal-ligand coordinationFlanco Zhuge¹, Salvatore Costanzo², Taisir Shahid¹, Charles-Andre Fustin¹, Jean-François Gohy¹, Dimitris Vlassopoulos², and Evelyne Van Ruymbeke¹

¹*Institute of Condensed Matter and Nanosciences, University Catholique de Louvain, Louvain-la-Neuve, Walloon Brabant 1348, Belgium;* ²*Department of Materials Science and Technology, FORTH, University of Crete, Crete, Greece*

The advent of dynamic metal-ligand (M-L) coordination has emerged as a powerful strategy for the design of self-assembled materials with stimuli-responsive properties. Among them, reversible polymeric networks obtained by functionalizing flexible polymer chains with M-L coordination are a promising avenue to engineer soft materials with tunable mechanical properties. In this work, we investigate the nonlinear shear and uniaxial extensional viscoelasticity of low-polydispersity (below 1.3) entangled poly (n-butyl acrylate) chains functionalized with terpyridine ligands. Upon self-assembly, the telechelic four-arm star precursors form model networks with minimum fraction of defects. Most of the chain segments participate in the entangled network, contrary to networks originating from linear chains with metal binding ligands along their backbone, which contain a large proportion of

dangling chain ends or loops. These model systems are therefore perfect to investigate how the dynamics of metallo-supramolecular bulk networks (MSBNs) is affected by both the dissociation kinetics of M-L complexes and the disentanglement process, and how these two mechanisms are coupled. The measurements are performed on a filament stretching rheometer and on a strain controlled rotational rheometer equipped with a cone-partitioned plate geometry. In extension the MSBNs show strain hardening at extension rates below their respective terminal relaxation times. Since the transient viscosity of MSBNs is measured at low strain rates, the strain hardening is attributed to the physical crosslinks which comprise M-L coordination. On the other hand, strong shear thinning behavior is observed at similar deformation rates in nonlinear shear flow. By altering the temperature, we systematically vary the relative importance of the M-L complexes, which allows us to determine their specific contribution to the network properties. Moreover, the properties of these systems can be finely tailored with varying the type or the nature of metal ions.

Thursday 15:10 Tritone

SM24

Rheology and Capillary Flow of Ionomers

Tanja Tomkovic¹, Savvas G. Hatzikiriakos¹, and Evan Mitsoulis²

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The capillary flow of a commercial ionomer melt was studied both experimentally and numerically. The excess pressure drop due to entry (Bagley correction), the effect of pressure on viscosity and the possible slip effects on the capillary data analysis have been examined. Using a parallel plate rheometer equipped with a partitioned plate, and a capillary rheometer with a series of capillary dies having different diameters, D , and length-to-diameter L/D ratios, a full rheological characterization has been carried out. The experimental rheological data have been fitted to a viscoelastic model (the K-BKZ model). Particular emphasis has been placed on the pressure-dependence of viscosity, with a pressure-dependent coefficient η_p . For the viscoelastic K-BKZ simulations, the time-temperature shifting concept has been used for the non-isothermal calculations, while the time-pressure shifting concept has been used to shift the relaxation moduli for the pressure-dependence effect. It was found that these viscoelastic simulations were capable of reproducing the experimental data well with significant effects resulting from the effect of pressure on viscosity, a parameter which cannot be neglected for this class of polymers. Moreover the effect of ionic interactions on the pressure drop has been assessed by comparing the results with those of a linear density polyethylene (LDPE) (parent polymer of this ionomer). Although the ionomer has a slightly smaller viscosity, its entry pressure drop is almost double than that of LDPE with vortices stronger and larger. These observations signify the effect of ionic interactions in flows that are presented for the first time in the literature.

Thursday 15:30 Tritone

SM25

Linear and non-linear rheology of hyper-branched EAA-cb-PP comb block copolymers

Carlos R. Lopez-Barron¹, Patrick Brant¹, and Maksim E. Shivokhin²

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A series of hyperbranched comb block (CB) copolymers with ethylene-acrylic acid (EAA; 4.5 mol.% AA) backbone and polypropylene (PP) side chains were synthesized via a condensation reaction between the acrylic acid groups on the commercial long chain branched (LCB) EAA polymer with hydroxyl-functionalized (atactic or isotactic) polypropylene vinyl-terminated macromonomers. Small-angle X-ray scattering (SAXS) measurements, in the melt, reveal nano-segregation of the PP side chains from the EAA backbone, which results in great enhancement in the shear and extensional rheology. Both the elastic and viscous moduli in the terminal regime increase (up to three orders of magnitude) as a function of PP side chain length and weight fraction. A second (low frequency) elastic modulus plateau is observed in CBs with high PP side chains (>40 wt%), suggesting formation of a weak network made of EAA chains connecting PP segregated domains. This network formation has a strong effect on the non-linear response of the CBs, namely, a very large extensional strain hardening is observed. The strain hardening strength (measured at Hencky strain of 2.5) increases from values of ~ 3 , for the neat EAA polymer, to ~ 100 , for some EAA-cb-PP compositions.

Thursday 16:20 Tritone

SM26

Viscoelasticity of Microphase Separated Brush Block Copolymers – Molecular Weight Dependence

Benjamin M. Yavitt¹, Huafeng Fei¹, H. Henning Winter², and James J. Watkins¹

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We report the linear viscoelastic behavior of poly(styrene)-block-poly(ethylene oxide) (PS-b-PEO) brush di-block copolymers. The molecular weight is increased by stepwise raising the backbone length while maintaining equal weight for the two blocks (symmetric diBB). The side chains are below the entanglement molecular weight for all samples. The diBBs readily self-assemble into microphase separated lamellar morphologies upon thermal annealing. The rate of structure development is much faster in diBBs than in conventional diblock copolymers. The increasing backbone length results in a direct increase of the lamellar spacing. diBBs are thermorheologically simple and maintain a gel-like rheological response even up to large molecular weights. Scaling relationships in the dynamic master curves show power law behavior analogous to critical gels. This study expands upon the understanding of the unique "gel-like" response of bottlebrush polymers and their advantageous processing potential.

Thursday 16:40 Tritone

SM27

Shear strain hardening and unusual stress relaxation after flow cessation of supramolecular living polymers

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We present a systematic investigation of the nonlinear shear rheology of a supramolecular living polymer at different concentrations and shear rates by means of stress start-up and relaxation test. In the transient regime we observe strain hardening before the overshoot and rationalize it by using a model based on the finite extensibility of elastically active strands. The examination of the model parameters and different transient quantities from the experiment suggest the presence of transient instabilities and shear banding at Weissenberg numbers (based on the breaking and reformation time) larger than one. The stress relaxation after cessation of steady shear flow is shown to provide insights into the mechanisms of association and response to flow in these living polymers. Two distinct relaxation modes are found. They are attributed to the breakage and reformation of hydrogen bonds responsible for the formation of the organogelator (fast time) and its overall motion (slow time). More importantly, for higher concentrations, i.e. stronger transient network, the stress relaxation is marked by an unusual intermediate local increase of stress before the eventual long-time relaxation. This counterintuitive phenomenon appears to be universal for associating supramolecular systems and is explained by the competition of Brownian motion and structure reformation of the broken species at the time of flow cessation.

Thursday 17:00 Tritone

SM28

Effect of polymer architecture on viscoelastic properties of Thermoplastic Elastomers

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Thermoplastic Elastomers (TPEs) are important class of segmented block copolymers. TPEs consist of hard segments (HS) and soft segments (SS) whereby, HSs capable of making supramolecular interactions via Hydrogen bonding and SS comprise of groups which are amorphous and shows low T_g . We investigating the viscoelastic properties of four linear well-defined segmented copolymers composed of polyTHF (SS) and T4T (HS) segments (5, 10, 15 and 20%). We observed the viscoelastic properties of these material are strongly dependent on their chain composition, thermal and deformation history. The fast association of HSs leads to formation of stable crystallites with large plateau modulus, which remains unaffected by thermal history. Whereas SS entanglements contribute to their dynamics at intermediate or high temperature via the HS association/dissociation process. Entanglements between associated HSs were found to be responsible for the sharp liquid-to-solid transition. The stability and melting temperature of these HSs domains have been found to correlate with the protocol of crystallite formation and, more specifically, the potential ability of HSs to avoid being trapped into metastable HSs domains. The trapping of HSs was also observed in FDSC measurements on fast cooling, as a result baby-ribbon crystals are formed. These crystals on heating, melts at low temperature as compared to stable ribbon crystals. To understand the effect of SS entanglement and position of the supramolecular group in the polymer chain, we synthesized the dumbbell architecture copolymers, keeping the same chemical composition of HS and SS. We varied the terminal HS densities (3,5 and 20%) in dumbbell architecture, making three samples different in SSs length (M_n - 11, 12 and 3K g/mol). Therefore in this work we address the effect of SS entanglements and chain architecture effect on the viscoelastic properties in terms of association/dissociation of HSs being at terminal position and relaxation of SSs entanglements.

Thursday 17:20 Tritone

SM29

Understanding and modelling the viscoelastic properties of metallo-supramolecular networks moving in a linear polymer matrix

Evelyne Van Ruymbeke, Juliette Blond, and Flanco Zhuge

Bio and Soft Matter - IMCN, Université catholique de Louvain, Louvain-La-Neuve 1348, Belgium

During these last years, several works have shown that combining supramolecular interactions and disentanglement dynamics within the same polymer systems can lead to very interesting viscoelastic properties. In particular, if the disentanglement time of the building blocks is longer compared to the average time during which a supramolecular sticker stays unassociated, then these two dynamics can have a synergistic effect and the terminal relaxation of the corresponding system can be much longer than the sticker lifetime. On the other hand, investigating and modelling the viscoelastic properties of binary blends composed of two monodisperse polymers still remains a challenge today. Especially, this requires taking into account the fact that the long chains can relax either by moving in a thin tube representing the influence of all the surrounding entanglements, or by moving in a dilated tube, which only considers the entanglements between long chains, but at the rhythm of the motion of the short chains. This also requires to properly consider the dynamic tube dilation effect induced by the short chains. In the present work, we combine these two research areas in order to investigate and model the relaxation of a metallo-supramolecular network composed of telechelic entangled star polymers which are diluted in a linear polymeric matrix. By varying the concentration of supramolecular stars as well as the molar mass of the linear polymers, we systematically investigate the influence of the short chains motion on the relaxation of the network. With the help of a statistical approach, the fraction of dangling arms in the network, the fraction of segments trapped between two crosslinking points, and the threshold concentration are determined. These results are then rationalized and are combined with the recently developed TMA tube model to describe the viscoelastic properties of supramolecular entangled polymers.

Thursday 17:40 Tritone

SM30

Linear-nonlinear dichotomy of nonlinear rheological behavior in polymer melts filled with particlesXiaorong Wang*School of Chemical Science and Engineering, Tongji University, Shanghai, Shanghai 200092, China*

We found an anomalous nonlinear behavior under large amplitude oscillatory shears, where the amplitude of stress deviates strongly from the linear dependence of strain, while the time dependence of stress remains sinusoidal. We named this phenomenon as "linear-nonlinear dichotomy", which is usually accompanied with the Payne effect in filled rubbers. In order to understand more molecular details regarding this "dichotomy", we examined a series of monodispersed polyisoprene polymers filled with carbon black. We found that the "dichotomy" emerges from a sharp transition as the molecular weight of the matrix, M_n , approaches and passes through a characteristic molecular weight M_c^* . The degree of entanglements plays a key role in the "dichotomy" rheology. A summary of recent research activities at Tongji on this subject will be given.

Symposium FP**Food, Pharmaceuticals & Cosmetics**

Organizers: Bruno de Cindio, Pietro Matricardi and Mats Stading

Thursday 14:30 Nettuno 1

FP1

Swelling of viscoelastic matrices by viscoelastic fluidsGianluca Chiarappa¹, Michela Abrami¹, Rossella Farra¹, Romano Lapasin¹, Gabriele Grassi², Mario Minale³, and Mario Grassi¹*¹Department of Engineering and Architecture, University of Trieste, Trieste, TS 34128, Italy; ²Department of Life Sciences, Trieste University, Trieste, Italy; ³Industrial and Information Engineering Department, University of Campania Luigi Vanvitelli, Aversa, Italy*

A typical example of viscoelastic matrices is represented by polymeric particles devoted to the controlled release of active agents (drugs) that swell when put in contact with an external solvent, typically a physiological medium. Although, in general, physiological fluids can be considered Newtonian, this is not always the case, let us consider, for example, the mucus present in different organs such lungs when affected by chronic obstructive disease (bacterial infections and cystic fibrosis, for instance). Swelling allows the release of the embedded drug due to the enlargement of the meshes of the polymeric network. The demand for more and more sophisticated drug delivery systems requires to theoretically study in high detail the mass transport phenomena involved in the swelling and release processes. The present study concerns with the mathematical modelling of both transport processes in the case of a viscoelastic matrix swollen by a viscoelastic fluid. While matrix viscoelasticity is accounted for by the generalized Maxwell model, a mean relaxation time accounts for fluid viscoelasticity. The model assumes that solvent uptake gives origin to an internal stress, due the polymeric network reaction to enlargement, able to affect solvent transport and thus, drug release. Despite the complexity connected to the theoretical description of stress and deformation in the swelling matrix, it is generally assumed that the stress state can be approximated by a scalar that can be viewed as an osmotically induced viscoelastic swelling pressure related to the trace of the stress tensor. At the same time, assuming incompressible materials and vanishing deformation gradient inside the matrix, deformation can be simply represented by a scalar quantity (the radial deformation in the case of spheres). Model simulations indicate that the higher the swelling solvent relaxation time, the lower the effect of matrix viscoelastic properties on mass transport phenomena

Thursday 14:50 Nettuno 1

FP2

Drug release in a micellar solution: a study based on DWS microrheologyDanila Gaudino¹, Mathias Reufer¹, Chi Zhang², and Frank Scheffold²*¹LS Instruments AG, Fribourg, Switzerland; ²University of Fribourg, Fribourg, Switzerland*

The dynamics of surfactant micellar systems depend strongly on their morphological structure. The low cost and the ability to define the rheological properties makes them suitable for an extensive range of applications [1]. One such application is the use of micellar carriers for non-steroidal anti-inflammatory drugs (NSAIDs) [2]. The aim of our work is to understand the influence of the release of the commercial medicine Aspirin in a well-known surfactant system based on Cetylpyridinium Chloride. The release process is monitored in-situ by following the time evolution of the viscoelastic properties of the sample by means of Diffusing Wave Spectroscopy (DWS) based bead microrheology and mechanical rheometer. DWS measurements are carried out by directly inserting a glass cuvette filled with the sample into a commercial DWS RheoLab III instrument with a recently released automatic calibration feature [3]. Both micro- and macro-rheological measurements show a transition from a Newtonian to a Maxwell-like behaviour as the Aspirin dissolves. Moreover, the Newtonian plateau viscosity of the system evolves in non-monotonic way, suggesting an elongation, first, and a shortening, later, of the micellar contour length. Similar results were reported previously for the sodic salt of the Aspirin, Sodium Salicylate [4, 5]. This agreement highlights the key role played by binding molecules in the determination of micellar shape and, thus, of the rheological characteristics of the overall system [4]. It also demonstrates the high potential of DWS microrheology may offer as a novel technique to monitor the release of commercial drugs, opening-up new avenue for the design of innovative carriers.

[1] Zana, R., & Kaler, E. W. (Eds.). (2007). Giant micelles: properties and applications (Vol. 140). CRC Press. [2] Pasquino, R. et al. (2016). Colloids and Surfaces B: Biointerfaces, 146, 938-944. [3] C. Zhang et al., to appear, <https://arxiv.org/abs/1711.01879> [4] Gaudino, D. et al. (2017). Physical Chemistry Chemical Physics, 19(1), 782-790. [6] Rogers, S. A. et al. (2014). Current opinion in colloid & interface science, 19(6), 530-535..

Thursday 15:10 Nettuno 1

FP3

A rheological and microstructural characterisation of MAGs organogel at different stearate/palmitate ratio for medical applications

Francesca R. Lupi¹, Valentina Mancina¹, Noemi Baldino¹, Ortensia I. Parisi², Luca Scrivano², Francesco Puoci², and Domenico Gabriele¹

¹DIMES Department, University of Calabria, Rende, Cs 87036, Italy; ²Department of Pharmacy, Health and Nutritional Sciences, University of Calabria, Rende, Cs 87036, Italy

Monoacylglycerols (MAGs) are well known for their ability in structuring oil phases creating organogels (or oleogels), and their use is widespread both in the food and in the cosmetic field. Usually, MAGs are commercially available as mixtures of glyceryl monopalmitate GMP (C₁₉H₃₆O₅) and glyceryl monostearate GMS (C₂₁H₄₂O₄) in different fractions according to the use. Considering this, there is still a lack of knowledge about the effect of GMS/GMP ratio on the rheological characteristics of the organogel. In this work, organogels were produced with different mixtures of GMP and GMS in olive oil, and the investigation was carried out with a rheological characterisation given by both small amplitude oscillation and steady in-flow tests. Rheological properties with temperature were also compared with a microstructural investigation based on IR spectra and a Rheo-optical analysis for the visual inspection of crystals forming the network. A number of samples were loaded with 5 fluorouracil (5-FU), a well-known chemotherapeutic active agent for adenocarcinoma, and its delivery with time from matrices was investigated with in-vitro tests, giving also an interpretation of the release mechanism.

Thursday 15:30 Nettuno 1

FP4

Controlled release of hydrophobic drug-ibuprofen using Fe-based nano biocomposite impregnated on a polymeric matrix

Sophia Varghese, Jai Prakash Chaudhary, and Chinmay Ghoroi

Chemical Engineering, Indian Institute of Technology Gandhinagar, Palaj Gandhinagar, Gujarat 382355, India

The controlled release of hydrophobic drugs which belongs to Bio-pharmaceutical Classification System (BCS) class II is of great interest in recent advances. Most of the Non-steroidal Anti Inflammatory Drug (NSAID) belongs to the class II and exhibit short life around (2 h). Ibuprofen is one such hydrophobic drug which is preferred for chronic, pain reliever for arthritis, rheumatics as well as post-operative conditions. Due to its short lifespan, the drug needs to be consumed intermittently. Also, it has carboxylic acid group which potentially damage the mucosal lining. The main objective of this study is to reduce the frequent intake, attain better therapeutic concentration, targeted site delivery and reduce the side effects. In this work, we investigate the controlled release of ibuprofen using smart drug delivery system of iron nano-composite impregnated polymeric matrix derived from seaweed biopolymer (Sodium alginate). In this study alginate templated iron nano-composite is prepared through calcinations followed by its impregnation in alginate beads for control drug release applications. Material characterizations were carried out by Powder X-ray Diffraction (P-XRD), Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), zeta potential measurement and Field Emission Scanning Electron Microscopy (FE-SEM). Drug loading and release performance were studied at different pH (7.4, 5.5 and 1.2) using UV-vis spectroscopy. The results show that Fe-based nano-composite impregnated polymeric matrix enhances the drug loading and pH-responsive behaviour by slower release of drugs in acidic medium. In addition, the results also exhibit controlled release of ibuprofen more than 20 h at 5.5 pH from smart drug delivery system prepared using biocompatible and naturally occurring bio-polymer having low toxicity (Sodium Alginate).

Thursday 16:20 Nettuno 1

FP5

Zeolites as support for anti-inflammatory drugs: rheology as a tool to track the release in a gel-like fluid

Rossana Pasquino, Danila Gaudino, Bruno de Gennaro, and Nino Grizzuti

Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

Surfactants are special molecules made up by a hydrophobic chain and a hydrophilic head. When dispersed in water, above a critical concentration value, they try to minimize the exposition of the hydrophobic part to the water. According to the packing factor, they can form different microstructures and the resulting rheological behaviour is strongly influenced. Molecular assembly can be easily tuned by addition of a binding salt to the solution which changes the packing parameter of the surfactant molecules. It has been recently found that nonsteroidal anti-inflammatory drugs (NSAIDs) can be used as penetrating salts and effectively and dramatically change the viscoelasticity of the dispersing fluid. This property can be used to control and track the drug release from specific supports. The aim of the current work is to study the release in a solution and in a gel like system of NSAIDs from zeolite supports. The materials are zeolite particles that, once modified on the surface, can be used as carriers for NSAIDs. The chosen NSAIDs are diclofenac and ibuprofen, both in sodic form. The release of the drug has been studied in a solution, simulating the intestinal fluid (PBS), and in a gel-like system, based on a surfactant (CpyCl) and a binding salt (NaSal). In the solution case, the quantity of drug released has been tracked via spectrophotometric assay whereas the release in the gel via rheological methods. The experimental results show that the molecular conformation of the NSAIDs is fundamental for the interaction with the zeolite surface and that the modified surface has a strong binding energy. In particular, the results in the gel-like system show that both NSAIDs behave as binding salts, thus changing the resulting rheological response, which suggests the possibility to use rheology to control and quantitatively measure the drug release.

Thursday 16:40 Nettuno 1

FP6

The rheology of environmentally friendly personal care productsChi Zhang¹, Thomas L. Rodgers², and James Winterburn³*The University of Manchester, Manchester M13 9PL, United Kingdom*

Cosmetic creams are necessities in people's daily life. Being semi-solid emulsions, most of creams are normally in a thermodynamically metastable state. Thus, surfactants are generally used in the formula of the products as emulsifiers and stabilizers, approximately accounting for 10-20 w/w%. Most industrially used surfactants are chemically synthesized, which shows poorly biodegradable and biocompatible. With the enhancement in concern for environment protection, considerable attention has been given to microbial surfactants (bio-surfactants) due to their environmentally friendly merits and higher surface activity. Many cosmetic processes are closely associated with the flow properties of materials, from manufacturing, packing to final use. Thus rheological measurements of cosmetic emulsions, where the flow and deformation behaviours of products can be revealed and predicted, are useful in the optimisation of manufacturing process and the development of consumer-satisfied products. This paper aims to study the effect of the cosmetic hand cream formulation with and without a bio-surfactant on the product rheology. The base system contains cetyl alcohol, glycerol monostearate, and Sodium lauryl ether sulfate with paraffin in water. Instead of the petroleum-based surfactants, the cream will be reformulated with microbial-derived surfactants, e.g. Sophorolipid and Mannosylerythritol lipids. The rheological measurements are carried out by analysing steady state shear flow, dynamic oscillatory, and creep-recovery tests. Droplet size analysis was also performed using a Mastersizer 3000 to understand the microstructure of the system and to link to the rheological results. Differential scanning calorimetry study was carried out to understand the thermodynamic properties of creams.

Thursday 17:00 Nettuno 1

FP7

The use of rheological measurements to study the stability of food and cosmetic emulsionsFabian Meyer, Fritz Soergel, and Klaus Oldoerp*Material Characterization, Thermo Fisher Scientific, Karlsruhe 76227, Germany*

Emulsions are mixtures of two or more immiscible liquids. In a two phase emulsion, one liquid forms a continuous phase in which the second liquid is dispersed in the form of small droplets. The most common types of these emulsions contain water and oil as continuous and dispersed phase. Depending on which liquid forms the continuous phase, either oil in water and water in oil emulsions are obtained. Due to the immiscibility of the liquid phases, emulsions are thermodynamically unstable and mechanical work is necessary to form a dispersed system. Emulsions are usually stabilized by adding amphiphilic molecules, so called surfactants, to improve their stability. Surfactants locate themselves at the interface of the two phases and reduce the interfacial tension. Furthermore they create steric hindrance or electrostatic repulsion that prevents the coalescence of two dispersed particles. Formulating stable multi component systems is of high importance for many daily consumer products such as cosmetic, personal care, pharmaceutical products as well as foodstuff. Rheology is used to investigate the flow and deformation behavior of liquid and semi-solid colloidal systems in order to optimize the application and processing. Traditional rheological methods in rotation and oscillation mode are used to gain valuable qualitative information on the stability and thus the shelf life of colloidal formulations. Rheological investigation of interfacial surfactant layers can help to obtain a deeper understanding of their emulsifying properties and ability to form stable multiphase systems. Finally combining rheometry with other analytical techniques such as microscopy or molecular spectroscopy enables a comprehensive investigation of multiphase systems and their structural changes. In this work the experimental results of rheological measurements carried on commercially available emulsions with traditional and combined techniques are presented and their potential use to determine stability and shelf life is discussed.

Thursday 17:20 Nettuno 1

FP8

Viscoelastic properties of plant polysaccharides impact mechanics and rheology of cellulose hydrogelsPatricia Lopez-Sanchez¹, Mauricio R. Bonilla², Marta Martinez-Sanz³, Si-Qian Chen⁴, Jason R. Stokes⁵, and Michael J. Gidley⁴¹*Product Design and Perception, RISE Research Institutes of Sweden, Gothenburg 40229, Sweden;* ²*Basque Center for Applied Mathematics, Bilbao, Spain;* ³*Instituto de agroquímica y tecnología de alimentos, Valencia, Spain;*⁴*CNAFS, The University of Queensland, Brisbane, Australia;* ⁵*Chemical engineering, The University of Queensland, Brisbane, Australia*

In the primary plant cell wall of growing plants, cellulose, hemicelluloses and pectins coexist in a highly confined and complex matrix. The contribution of these components to the unique rheological properties of plant cell walls is determined by their hierarchical organisation. A full picture of cell wall structure-property relationships is still lacking, due to the complexity and heterogeneity of plant materials. In this work a bottom-up approach has been taken using bacterial cellulose composites as a simplified model for plant cell walls. Hemicelluloses and pectins can be spontaneously assembled into the cellulose scaffold during cellulose synthesis. Mechanical investigations revealed that the viscoelastic properties of the plant polysaccharides have a direct impact on the compression-relaxation and rheological behaviour of the composites. The poroelastic nature of the composites makes it possible to characterise these materials under compression and calculate permeability, axial and radial moduli. Our results provide insights into the roles of different plant polysaccharides in cell wall mechanics and aim at assisting design of biomimetic cellulosic-based products.

Thursday 17:40 Nettuno 1

FP9

A rheological approach to bigel investigation

Domenico Gabriele, Francesca R. Lupi, Noemi Baldino, and Bruno de Cindio

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Biphasic (oil/water) systems are used in many areas (cosmetics, pharmaceuticals, foods) owing to their specific macroscopic properties. Different systems are being proposed in recent years, among them bigels (or biphasic gels) seem particularly interesting because they are composite materials in which a structured phase (based on oil or water) is dispersed in a gelled continuous phase (based on a solvent different from that used in dispersed medium). Owing to their nature, they have the positive features of hydrogel, organogel and two-phase systems. Despite of the growing interest in these systems, there is still a lack of knowledge on the relationship between their macroscopic rheological properties and the single structured phases. In the present work a rheological study of bigels was carried out with the aim of investigating thermal stability and microstructure and trying to relate macroscopic properties, such as dynamic moduli, to characteristics of single phases (such as the gelling agent content) and to their volumetric ratio. The rheological modelling of these systems was explored, starting from literature models for composite systems, with the aim of determining a relationship suitable for designing bigels with controlled rheological properties. An empirical modification of literature models was proposed to describe the specific behaviour of bigels obtaining, as a final result, a good fitting of experimental data.

Symposium IP**Industrial Rheology & Processing**

Organizers: Paulo Roberto de Souza Mendes, Dino Ferri and Joao Maia

Thursday 14:30 Nettuno 2-3

Keynote IP1

Blending microcrystalline and resin constituents of a chewing gum: dependence of the blend viscoelastic properties on the temperature historyMarco Delmonte¹, Marina Muccioli¹, Simona Carotenuto³, Rossana Pasquino⁴, and Nino Grizzuti⁵¹Research Dept., Perfetti Van Melle spa, Lainate, Italy; ² Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

Chewing gum is a complex viscoelastic system, characterized by components, chemically and physically different. The "ingredients" of the gum base, which is the main constituent of a Gum, can be classified into crystalline materials (i.e. wax, HVO), amorphous components (i.e. PIB, IIR ..), resins or resin based materials (i.e. terpene and rosin ester resins,...), PVAc, fillers (i.e. calcium carbonate...) and plasticizers (i.e. vegetable mono-diglycerides). The thermal history of the gum base during the processing conditions can influence the final properties of the product and, as such, its success. The compatibility between different components determines the viscoelastic properties and their thermal behavior. The aim of this work is to study the viscoelastic properties and the calorimetric transitions of some of the gum-base components during a temperature ramp from room temperature to 120°C, and viceversa. More specifically, a microcrystalline component (Hydrogenated triglycerides from Soy) blended with a plasticizer (Hydrogenated mono-diglycerides from Sunflower) is mixed with two different types of resin. The rheological response during the thermal ramps coupled with the heat exchange shown in the calorimetric analysis shed a clear light on the crystallization transitions occurred upon temperature changes. More specifically, it has been found that the crystallization temperature is strongly influenced by the resin's coexistence with the crystalline phase and that the crystallization kinetics depends strongly on the type of added resins. A systematic rheological and calorimetric study has been performed by tuning the thermal rate used during the temperature ramp, in a way to study the crystallization transitions upon thermal history and the differences with the ones occurred with the single components. The influence of the addition of a solid filler to the blends has been analyzed too and it has been found that it acts as a nucleation site for the crystalline phase, by accelerating the crystallization process.

Thursday 15:10 Nettuno 2-3

IP2

How rheological properties affect fine line screen printing of pastes: a combined rheological and high-speed video imaging study

Chenhui Xu and Norbert Willenbacher

Institute for Mechanical Process Engineering and Mechanics, Karlsruhe Institute of Technology, Karlsruhe 76131, Germany

Fine line screen printing dominates the front side metallization of silicon solar cell due to its high throughput and low cost. The market chases a narrower electrode for less light loss and a higher electrode for a better electronic performance. Riemer discussed the basic parameters of screen printing and introduced an analytical model of the process. Hoornstra et al. applied oscillation tests to simulate the screen printing process but the long timescale they used in their experiments is not relevant to the screen printing process. However, screen printing has never been investigated directly to extract reasonable process and material parameters. In this study, a high-speed camera is inserted into a commercial screen printer in order to investigate the flow of the paste pushed through the screen open and its spreading on the substrate. The silicon wafer is replaced by a transparent glass plate for observation of the process from the bottom side. Three samples are formulated with different amounts of thixotropic agent, varying the yield stress. Another set of samples with varying viscosity at high shear rate is obtained by adding different amount of polymer. The break-up of the pastes is characterized using filament stretching experiments. Several process parameters deduced from high-speed imaging of the printing procedure are discussed for model pastes: the pre-injection zone, i.e. the distance ahead of the squeegee position where the rolling paste is already pushed through the screen openings; its length is linearly related to the reciprocal of yield stress; the cling

zone, i.e. the corresponding area where the screen attached to the substrate due to the paste adhesion; its length is linearly related to the fracture strain. Paste spreading is observed at the finger and busbar connection area but no detectable spreading at fine line area. A simple model relates the electrode width with the reciprocals of yield stress and high shear viscosity.

Thursday 15:30 Nettuno 2-3

IP3

Assessment of reinforcement in polymer nanocomposites using cumulative rheological parameters

Milan Kracalik

Institute of Polymer Science, Johannes Kepler Universität Linz, Linz, Austria

Polymer nanocomposites exhibit complex rheological behaviour due to physical and possibly also chemical interactions between individual components (polymer, nanofiller, compatibilizer in case of unpolar polymer), which can be detected by rheology. Usually, flow behaviour of multiphase polymer systems has been described by storage flow part through the storage modulus curve (formation of secondary plateau) and by loss flow part through dumping behaviour (e.g. Van Gurp-Palmen-plot, Cole-Cole plot), respectively. On the contrary to typical rheological analysis, new approach using information about storage flow part has been introduced for description of physical network made of rigid particles in polymer matrix as relation of JG''/JG' over specific frequency range. This approach has been experimentally proved for polymer nanocomposites in order to evaluate both shear as well as elongational flow field. In this contribution, polyethylene-clay-ZnO and polyethylene-clay-TiO₂ nanocomposites with different dispersion grades have been prepared and changes in physical network have been analyzed by novel "melt rigidity" approach using different cumulative rheological parameters. It has been found that information obtained from specific cumulative rheological parameters allows clear comparison even of small differences in physical network of nanocomposites. This new approach was in good accordance with information gained from conventional evaluation approach like shear-thinning or G' secondary plateau analysis.

Thursday 16:20 Nettuno 2-3

IP4

Linear and nonlinear shear rheology of low percolation graphene polymer nanocomposites

Roland Kádár¹ and Thomas Gkourmpis²

¹*Industrial and Materials Science, Chalmers University of Technology, Gothenburg SE-412 58, Sweden;* ²*Innovation & Technology, Borealis AB, Stenungsund SE-444 86, Sweden*

The rheology of specially designed graphene - isotactic polypropylene nanocomposites prepared via batch melt mixing is explored in this study. The studied nanocomposites stand out through their low electrical percolation threshold, comparable to those achieved for solution blending. In comparison, commercially available graphite nanoplatelets in similar preparation conditions reach percolation thresholds that require significantly higher filler content with comparatively reduced electrical and thermal properties. Linear and nonlinear oscillatory shear tests were performed on an Anton Paar MCR702 TwinDrive rheometer. The nonlinear analysis was performed in the framework of Fourier-Transform analysis and Tchebyshev polynomial decomposition. Complementary, microstructural, electrical, thermal, and mechanical properties were also determined. The rheological percolation threshold was determined with superior sensitivity using nonlinear material parameters. In linear viscoelastic frequency sweeps, the additional elastic contribution of the filler network buildup was difficult to detect in the limit of low angular frequencies. This was observed for samples above the percolation threshold, and with a pronounced character in the conductor regime. In contrast, at the electrical percolation threshold, the shear stress nonlinearities disclose a comparatively strong angular frequency dependent material response. This was quantified by the relative third higher harmonic (I31) intrinsic nonlinearity slope, and consequently the Q-nonlinear coefficient. A similar behavior is recorded in the elastic and viscous relative third higher harmonic Tchebyshev coefficients (e31, v31). Notably, e31 becomes positive above 1 rad/s. Almost identical zero-strain Q-nonlinear coefficients are recorded below percolation, with a similar behavior recorded for e31 and v31 (positive). Above the threshold, e31 increase in magnitude whereas v31 becomes dominantly negative.

Thursday 16:40 Nettuno 2-3

IP5

Rheology and processing of polymer nanocomposites with graphene and other 2D materials

Leice G. Amurin, Yuri D. Oliveira, Camila F. Oliveira, Pablo A. Munoz, Camila L. Rodriguez, Guilhermino J. Fechine, and Ricardo E. Andrade

MackGraphe - Graphene and Nanomaterials Research Center, Mackenzie Presbyterian University, São Paulo, SP, Brazil

After it was isolated in 2004, graphene and other bi-dimensional (2D) nanomaterials became of great interest, scientific and technological, due to their unique properties. Such nanomaterials have shown excellent properties such as enhanced mechanical, thermal, and electrical response. These properties are advantageous for a wide range of relevant industrial applications (i.e., food packaging, automotive, airplane, sport products, textile, electronic devices, and coatings/inks). Nowadays they are extremely appealing to polymer nanocomposite processing due to the interplay role of nanofillers once embedded in a polymer matrix. Among the different methodologies of incorporating 2D nanofillers in a polymer matrix, melt blending is usually the most economical and industrial-scale approach. However, the effective polymer-filler interaction is still a challenge due to poor filler dispersion and polymer-filler interfacial adhesion mechanisms. In this study, we compare different mixing protocols in order to disperse 2D materials (Graphene oxide, Molybdenum disulfide) into polymer matrix (polystyrene, thermoplastic polyetherethylenes, polypropylene, styrene-ethylene/1-butene-styrene) by using a twin screw extruder. Processing parameters such as screw velocity, and materials properties as filler concentration, and degree of dispersion were investigated. The aim is to address the thermodynamics and the physical-chemical interactions, which may be involved during the mixing and dispersion process. In particular, graphene nanofillers are found to significantly affect the rheological response of the polymer matrix. Depending on the exfoliation level, they can behave as a lubricant, where the viscosity decreases with the particles. Our preparation and processing protocols for polymer nanocomposites with 2D nanofillers are shown to be very efficient in terms of filler dispersion, and consequently, obtaining materials with excellent properties, such as mechanical, starting at very low filler content (some cases less than 0.5% w/w).

Thursday 17:00 Nettuno 2-3

IP6

Correlation between polymer and powder characteristics and the properties of items produced by means of the rotational molding technique

Dino Ferri, Erika Saetti, Fabio Gandolfi, and Francesco Scavello

Claudio Buonerba Research Centre, versalis spa, Mantova 46100, Italy

Rotational molding is a complex process in which rheological properties of the polymer melt and its powder may play a key role. On the one hand the ability of the material to exchange heat with the mold and properly cover it depends on the powder flowability. On the other hand the melt viscosity may be crucial for the bubble gas entrapment phenomenon which generally leads to insufficient impact properties of the items produced. Finally the surface gloss may be driven by both powder particle size distribution and melt rheological properties. In this work several HDPE and LLDPE powders with different morphology and particle size distribution were prepared and investigated. They were all characterized in terms of powder flowability and particle shape and melt flow viscosity. Using a standard simple cubic mold all these powders were rotationally molded using different cycle temperature and time conditions. These were chosen to enhance some critical aspects of the process here investigated like air bubble entrapment, surface roughness and impact resistance. All these properties were then carefully investigated for each item produced with the aim of correlating them to the powder and melt rheological behaviour and features. The final result of this work has been to highlight which are the most important features of the polyethylene grade and powder to be taken into account if one needs to obtain an improvement of the items quality and performance.

Thursday 17:20 Nettuno 2-3

IP7

Computer simulations and experimental studies of extrudate swell in monodisperse and polydisperse polystyrenes

Ben Robertson¹, Richard L. Thompson¹, and Tom C. McLeish²

¹*Department of Chemistry, Durham University, Durham, County Durham DH13LE, United Kingdom;* ²*Department of Physics, Durham University, Durham, County Durham DH13LE, United Kingdom*

We describe the finite element simulation and experimental studies of extrudate swell in a range of polystyrenes. We use the tube model based Rolie-Poly constitutive equation to predict extrudate swell for a range of linear polystyrenes and show that any molecular weight dependence of the swelling can be removed when the flow speed is scaled by the Rouse Weissenberg number. We also present isothermal extrusion experiments on the same polymers and can obtain good predictions well into the strong chain stretching regime. The predictions for swelling ratios match those from experiments up to Rouse Weissenberg numbers of 7. An over prediction in extrudate swell is seen above this point, attributed to a reduction in monomeric friction at high stretching rates. We present simulations of polydisperse polystyrenes using a multi-mode polydisperse version of the Rolie-Poly equation and compare to extrusion experiments on these polymers. A good fit is observed between simulation and experiment, meaning these simulations can be extended to more polydisperse, industrially relevant samples.

Thursday 17:40 Nettuno 2-3

IP8

A full model for flow-induced, multi-phase, multi-morphological crystallization of isotactic polypropylene: application to inhomogeneous slit flow

Giovanna Grosso¹, Enrico Troisi², Patrick D. Anderson¹, and Gerrit W. Peters¹

¹*Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands;* ²*Sabic, Geleen, The Netherlands*

Depending on the conditions, isotactic Polypropylene (iPP) can form different crystalline phases. This can be clearly observed in injection molding samples. Using X-ray scattering methods, a distribution of four different phases (α , β , γ , meso) over the thickness of the sample is found. From several experimental methods, including extended dilatometry (PVT) the multi-phase, multi morphology (shish-kebab, cross-hedging also known as parent and daughter structures) crystallisation kinetics were determined. Next, we used a prototype industrial flow device (piston driven slit flow) combined with in situ wide angle X-ray diffraction and small angle X-ray scattering to measure the evolution of the (oriented) crystalline structures and phases (α , β , γ ,) for different flow conditions. We developed an accurate numerical model able to describe flow induced crystallization of isotactic polypropylene at high pressures and shear rates. The finite element model includes a full coupling of nonlinear viscoelasticity, compressibility, non-isothermal flow and flow induced crystallization equations. The slit flow is used as a test case that is simulated at a wide range of imposed pressures and piston speeds. The build up and relaxation of the pressure difference and the development of the different structures and phases during and after flow are accounted for. Quantitative agreement with experiments is obtained. To our knowledge, this is the first time that such an extended modeling is presented.

Symposium PS

Polyelectrolites, Self Assembling Fluids & Gels

Organizers: Dganit Danino, Vincenzo Guida and Laurence Ramos

Thursday 14:30 Nettuno 4

PS14

Exploring shear thickening of telechelic associating polymers through stochastic simulationsGun Woo Park¹ and Giovanni Ianniruberto²¹*Institute of Complex Systems ICS-3, Forschungszentrum Juelich, Juelich 52428, Germany;* ²*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

Hydrophobically modified ethoxylated urethane (HEUR) is one of the most popular examples of telechelic associating polymer. In a certain range of HEUR concentration in aqueous solution, (i) linear viscoelasticity follows a single-Maxwellian behavior with a characteristic time controlled by the network relaxation due to association/dissociation kinetics. In simple shear flows, HEUR systems often (ii) exhibit strain hardening in the transient startup when the shear rate exceeds the reciprocal relaxation time, and (iii) at steady state deviate from the Cox-Merz rule, deviations including (iv) a shear-thickening phenomenon. Recently, Park and Ianniruberto [1] suggested a new stochastic simulation to describe the complex rheological behavior listed in (i-iv). The results indicate that finite extensibility effects are mostly responsible for the strain hardening, while deviations from the Cox-Merz rule are due to the persistence of bridge chains. However, the detailed mechanism behind the shear thickening is still unclear. In this study, we show additional observables by using the same simulation method for a better understanding of the shear-thickening phenomenon. Furthermore, we extend the range of the parameter space explored in [1] by examining larger (and more reasonable) values of the ratio between the loop dissociation time and the Brownian diffusion time of flower-like micelles.

[1] Park, G. W., & Ianniruberto, G. (2017). *Journal of Rheology*, 61(6), 1293-1305.

Thursday 14:50 Nettuno 4

PS15

The self-assembly and aggregation of nanocrystalline cellulose in two and three dimensionsPascal Bertsch and Peter Fischer*Institute of Food, Nutrition and Health, ETH Zurich, Zurich 8092, Switzerland*

Nanocrystalline cellulose (NCC) is a renewable nanomaterial gained from wood pulp. NCC is capable of forming charged stabilized suspensions, glasses, and liquid crystalline phases. Reducing NCC electrostatic repulsion induces formation of hydrogels. Besides aggregation in 3D, NCC is able to adsorb and assemble at 2D interfaces. Here we aim at understanding the role of the governing intermolecular interactions in both 3D and 2D cellulosic structures. We found that salt addition allows to control the phase behavior of NCC by modulating its zeta-potential. Starting from isotropic NCC suspensions, salt addition favored the formation of nematic liquid crystals in contrast to Onsager's hard rod repulsion theory. The nematic ordering is attributed to an increased intermolecular attraction favoring lateral arrangement. This finding allows to exploit NCC nematic ordering capacity at lower NCC concentrations. At higher salt concentrations NCC crystallites aggregated and formed hydrogels. Gel strength was found to be independent of salt valency, indicating that NCC gelation is governed by intermolecular attraction rather than cationic bridging. NCC is able to adsorb at air/water interfaces. As in 3D suspensions, the adsorption behavior and interfacial layer properties strongly depend on electrostatic interactions. Beyond salt concentrations that allow intermolecular interactions adsorption kinetics were increased and a sudden increase in interfacial elasticity observed. Thus, modulating NCC intermolecular interactions allows the formation of 3D and 2D cellulosic materials with tailored properties.

Thursday 15:10 Nettuno 4

PS16

Unusual self-assembly behavior of polyelectrolytesPranav Sudersan¹, Mehak Jain², Kamendra Sharma², and Jyoti R. Seth¹¹*Chemical Engineering Department, Indian Institute Of Technology - Bombay, Mumbai, Maharashtra 400076, India;*²*Chemistry Department, Indian Institute Of Technology - Bombay, Mumbai, Maharashtra 400076, India*

Polyelectrolytes with high charge density such as DNA are known to self-assemble into rod-like or toroidal nanostructures in the presence of multivalent counter-ions in the solution, a process known as DNA condensation. The seemingly attractive forces between like-charged DNA chains driving the self-assembly mechanism have been attributed to counterion correlations. Such correlations are absent when the system has monovalent counterions. Recently, certain polyelectrolytes have been observed to self-assemble into fibrillar structures in the presence of monovalent counter-ions within a specific range of solution conditions. The fibrils formed are micron sized, unlike the nano-scale fibrils formed by comparable materials like polypeptides. The self-assembly process is also observed to be irreversible in nature. To understand this process, which cannot be explained by counterion correlations, we have used classical Poisson-Boltzmann and Manning-Oosawa counterion condensation theories to suggest a possible mechanism for such unusual self-assembly of polyelectrolytes. The Poisson-Boltzmann theory is used to model the electrostatic interactions between polyelectrolyte chains and together with Manning's theory gives us the counterion profile around the chains. The enhanced translational entropy from sharing of condensed counterions between chains and its effects on polyelectrolyte conformations can explain the basis for such fibrillar self-assembly. In this talk, theoretical predictions will be validated against experimental findings for formation of fibrils from polyelectrolyte solutions.

Thursday 15:30 Nettuno 4

PS17

Viscosity of polyelectrolyte solutions as a function of composition in the absence and in the presence of extra salt

M Bercea¹, X. Xiong², and B. A. Wolf³

¹*Institute of Macromolecular Chemistry, Petru Poni, Iasi, Romania;* ²*Department of Materials Science and Engineering, Xiamen University, Xiamen, China;* ³*Institute of Macromolecular Chemistry, University of Mainz, Mainz, Germany*

As long as the viscosity η constitutes a function of state, its dependence on polymer concentration c (mass per volume) can be modeled with high accuracy over the entire range of composition by means of the following relation: $\ln \eta_{\text{rel}} = (c[\eta] + \alpha \cdot c^2[\eta]^2)(1 + \beta \cdot c[\eta] + \gamma \cdot c^2[\eta]^2)$, where η_{rel} is the relative viscosity (solution/solvent) and $c[\eta]$ stands for the reduced polymer concentration (normalized to the intrinsic viscosity $[\eta]$ of the polymer); α , β and γ represent adjustable parameters. In the majority of cases the parameters β and γ suffice to describe the experimental findings; for polyelectrolytes α is often needed in addition. The introduction of a generalized intrinsic viscosity, $\{\eta\}$, according to $\{\eta\} = (\partial \ln \eta / \partial c)$, helps the understanding of polymer solutions; in the limit of infinite dilution $\{\eta\}$ becomes identical with $[\eta]$. The lecture presents the following examples for the application of the above equations: (i) dependence of $[\eta]$ on the concentration of extra salt in the solvent; (ii) establishment of master curves (iii) ion-specific effects on the solution viscosities (iv) coil dimensions and coil overlap as a function of polymer concentration (v) modeling of the viscosities over the full range of composition; (vi) determination of glass transition temperatures.

Symposium LA

Living & Active Matter

Organizers: Pietro Cicuti, Antonio De Simone and Gerhard Gompper

Thursday 16:20 Nettuno 4

Keynote LA1

Dynamics and rheology of active particles in microchannel flows

Hemalatha Annepu¹, Kai Qi¹, Adam Wysocki², Gerhard Gompper¹, and Roland G. Winkler¹

¹*Institute of Complex Systems, Forschungszentrum Jülich GmbH, Jülich, Germany;* ²*Theoretical Physics, Saarland University, Saarbrücken, Germany*

The swimming behavior of active objects such as bacteria, algae, or synthetic colloidal particles is strongly influenced by the presence of nearby boundaries. Even more, external flows, e.g., pressure driven or shear flows, give rise to an intriguing dynamical behavior such as upstream swimming or a decreasing viscosity with increasing concentration. Thereby, the emergent complex dynamical behavior is governed by hydrodynamic interactions between the active objects and present surfaces. We study the dynamical properties of an active suspension under flow in a microchannel. An active object is described as a spheroidal particle with a prescribed tangential surface velocity, a so-called squirmer. The fluid is modelled by the multiparticle collision dynamics approach, a particle-based mesoscale simulation method, which includes thermal fluctuations and hydrodynamic interactions. By tuning the model parameters, puller-, pusher-, or ciliate-like dynamical behavior is obtained. In microchannels far from the surfaces, the swimmers typically follow the external flow with on average a sinusoidal trajectory. Near the surfaces, where hydrodynamic interactions are most pronounced, pullers and pushers show a qualitatively different behavior. Individual pushers swim upstream near the wall for propulsion velocities exceeding the flow velocity, but there is no average upstream flux. Pullers swim upstream for propulsion velocities far larger than the fluid velocity, whereas they change to downstream swimming with increasing flow velocity. Beyond a certain swimming velocity, we observe migration orthogonal to the flow field. The individual swimming patterns will be discussed.

Thursday 17:00 Nettuno 4

LA2

Formation and dissociation of VWF-platelet aggregates in blood flow

Masoud Hoore, Gerhard Gompper, and Dmitry A. Fedosov

Institute of Complex Systems, Forschungszentrum Jülich, Jülich, Germany

von Willebrand factor (VWF) and blood platelets play a key role in blood clotting by forming VWF-platelet aggregates. Such aggregates form at high shear rates and dissolve reversibly at low shear rates, which leads to an interesting behavior of these aggregates in microvessels. In blood flow, red blood cells (RBCs) migrate to the center of a vessel and facilitate margination (or migration) of both VWF molecules and platelets toward vessel walls. In the near-wall region, where the shear rate is largest, VWF-platelet aggregates start forming and grow. After reaching a certain size, such aggregates penetrate into the bulk flow populated by RBCs, where local shear rates are relatively small, and dissociate reversibly to single components. Consequently, this process continues in the steps just described. Using mesoscale hydrodynamic simulations, we investigate the formation and dynamics of VWF-platelet aggregates in blood flow. We show that shear activation of VWF and the interactions between VWF and platelets are the main determinants of this process. Thus, a significant change in the VWF shear activation or VWF-platelet interactions may lead to no aggregate formation or to the formation of irreversible aggregates.

Thursday 17:20 Nettuno 4

LA3

Activity modifies shear-thinning rheology in dilute suspensions of kinesin-driven microtubulesClaudia Dessi¹, David A. Gagnon¹, Daniel Blair¹, and Zvonimir Dogic²¹*Department of Physics, Georgetown University, Washington DC, DC 20057, United States;* ²*Department of Physics, University of California - Santa Barbara, Santa Barbara, CA 93106-9530, United States*

We will present the rheological response in terms of apparent viscosity of a unique class of biologically-derived, extensible active suspension using fluorescence-labeled stabilized bundling microtubules and kinesin motor proteins, which are driven by adenosine triphosphate (ATP). Compared to conventional passive systems, active suspensions are in perpetual out-of-equilibrium where individual particles in the fluid inject energy at a length scale corresponding to their hydrodynamic length scale through self-propelled motion. This behavior can produce significant local fluctuations in concentration, viscosity, and fluid velocity, as each particle or swimmer translates ballistically at short time scales and super-diffusively during longer observation. We investigate its mechanical properties in a low shear thinning medium by simply coupling traditional rotational strain controlled rheometry techniques, which provide information about the suspension's bulk response, with fluorescence microscopy particle tracking techniques, which link the activity and microscale dynamics to macroscopic measurements. Using these techniques, we seek to directly address the role of activity of an isotropic bundling microtubule suspension under an applied external shear flow. We observe a significant increase in shear thinning behavior in the active microtubule suspension compared to its buffer medium. We then address the potentially link to the activity of the suspension, which is controlled by ATP and microtubule concentration. Finally, we demonstrate that active microtubule suspensions are found to be a suitable candidate for investigating the effects of activity on the mechanical properties of viscoelastic media, opening a new branch of future investigations for biologically-relevant fluids with non-Newtonian properties.

Thursday 17:40 Nettuno 4

LA4

Flow induced by active intestinal mucosa at macro- and micro- scalesClément de Loubens¹ and Roger G. Lentle²¹*CNRS, Univ. Grenoble-Alpes, GIERES, France;* ²*Massey University, Palmerston North, France*

Controlling the spatio-temporal delivery of drugs or nutrients in the gastro-intestinal tract is of prime importance to improve pharmaceutical treatments or to control the nutritional properties of food products. The major constraints to such mixing are the high viscosity and the non-Newtonian characteristics of the gastro-intestinal content and the low velocity of the active mucosa, which together result in low Reynolds numbers. It is most likely that transfers in the lumen should limit biochemical reactions. Hence, it is essential to understand and model the mixing strategies developed by the digestive tract. To identify the relevant biomechanical and rheological factors that limit mixing and absorption in the small intestinal lumen, we have developed methods of high fidelity quantification of intestinal motility, coupled to realistic models of intestinal fluid dynamics as well at the scale of smooth muscle activity (1 mm), as at the one of villi, finger-like structures of around 500 μm length covering intestinal mucosa. At macroscopic scale, we show that activity of smooth muscles are organised into domains of contractions. This activity is responsible for a process of shear dispersion of the luminal content in the longitudinal direction. At microscopic scales, villous movement during longitudinal contractions is a major radial mixing mechanism that increases dispersion and absorption around the mucosa despite adverse rheological properties of the digesta. Finally, we conclude that the intestinal mucosa can be considered as an active microfluidic mixer [1-4].

[1] Lim, Y. F. et al. (2015). *Food & function*, 6(6), 1787-1795. [2] Lentle, R. G., & De Loubens, C. (2015). *Journal of Comparative Physiology B*, 185(4), 369-387. [4] de Loubens, C. et al. (2014). *PloS one*, 9(4), e95000. [4] De Loubens, C. et al. (2013). *Journal of the Royal Society Interface*, 10(83), 20130027.

Symposium BE**Blends, Emulsions, Foams & Interfacial Rheology**

Organizers: Ernesto Di Maio, Peter Van Puyvelde and Jan Vermant

Thursday 14:30 Nettuno 5-6

BE26

Carbopol: from a simple to a thixotropic yield stress fluidMaureen Dingre¹, Mina Fazilati¹, Morton M. Denn², and Daniel Bonn¹¹*Institute of Physics, University of Amsterdam, Amsterdam, The Netherlands;* ²*Levich Institute, City College of New York, New York, NY, United States*

There is an ongoing discussion in the literature about the flow behavior of the widely used model yield-stress fluid Carbopol. Some papers show that it is indeed the model yield-stress fluid that many people believe it to be. However, other authors report rheological hysteresis in the flow curve, transient shear banding that persists for a very long time, and the breaking of fore-aft symmetry in a falling ball experiment. Such behaviors have in the past been associated with thixotropic yield stress fluids, which are very different from simple ones. We present experiments that suggest that both types of behavior may be found in the same type of Carbopol, depending on the preparation: after strong stirring for a long time, the system becomes slightly thixotropic. Flow visualization experiments, with fluorescently labeled Carbopol, elucidate the difference between simple and thixotropic behavior of the systems: the stirring breaks the polymers into smaller fragments, some of which are so small that they exhibit Brownian motion. We propose that this generates a depletion interaction that leads to gel formation, which in turn leads to the thixotropy.

Thursday 14:50 Nettuno 5-6

BE27

Viscoplastic water-entryMaziyar Jalaal, Dave Kemper, and Detlef Lohse*Physics of fluids, University of Twente, Enschede, The Netherlands*

Viscoplastic (a.k.a. yield stress) fluids are materials that do not deform when undergoing a shear stress smaller than a critical value (yield stress). Above the yield stress, however, they behave like a viscous fluid (typically with a nonlinear viscosity). We performed experiments and theoretical studies on the impact of droplets made from viscoplastic fluids on a water surface. In experiments, we change the size, impact velocity, and the rheological properties (e.g., yield stress) of the droplets and observe the dynamics using high-speed imaging. Before the impacts, the droplet sustains the shape due to the presence of the yield stress. Nevertheless, the droplet deforms while passing through the water interface and eventually retains its shape shortly after entering the water phase. We show that the dynamics and more importantly the final shape of the droplets strongly depends on the rheological properties. For a given impact velocity, the final shape can vary from slightly deformed "pear-like" shape (for a large yield stress) to a highly deformed "Mexican hat" shape (for a soft gel). We introduce the relevant non-dimensional numbers and present the regime map of the final shapes. We also show the numerical simulations of the same problem, where we use a regularised Herschel-Bulkley model in combination with finite volume and volume-of-fluid and techniques. In the simulations, we discuss the yielding regions inside the droplet in more details and shows the similarities and differences in comparison to the experiments.

Thursday 15:10 Nettuno 5-6

BE28

From recycled polymers waste to microfibrillar compositesMojtaba Kharghanian, Sylvie Dagréou, Fabienne Grandchamp, and Frédéric Léonardi*IPREM, University of Pau, PAU 64000, France*

Recycling the polymer wastes from packaging in new products is a priority of lots of country and last summer China reduces drastically the amount of importation of European polymer wastes. The main objective of this work is to prepare and study the properties of opaque PET/PP blends. Transparent PET is widely used for water and soft drinks packaging but recently some milk bottles for example have been prepared, using injection blow moulding, with opaque PET containing titanium dioxide as white colorant that can hardly be integrated into the conventional waste treatment chain. PET and PP form immiscible polymer blends and stabilizing the morphology through the use of additives is a real challenge. Some compatibilizers (block copolymer, clays or nanoparticles) can be added into polymers blends to reduce the size of dispersed phases by preventing coalescence in order to improve physical properties as thermal, rheological, mechanical. Some studies are dedicated to PET/PP blends, but few are based on recycling polymer waste and virgin pellets are commonly used. Originality of our work relies on the use of opaque PET flakes and PP waste from automotive battery cell products with potential applications in non-food areas (such as automotive or construction). The choice of PET/PP blend is also related to the possibility to obtain some microfibrillar composites (PP as matrix and PET as micro-fibers) that can be replace classical PP/GF composites, as the two melt temperature are quite different. These recycled polymer waste blends (and compatibilised ones) are prepared by twin screw extrusion and deeply characterised by rheology in shear flow (thermal stability, viscoelastic properties, thermo-mechanical analysis) and by DSC. Finally, we try to link morphology deduced by TEM images and structural information derived from flow properties. This study is done in the framework of a trans-border French/Spain project REVALPET (POCTEFA).

Thursday 15:30 Nettuno 5-6

BE29

Effects of ionic liquids and thermal annealing on the rheological behavior and electrical properties of poly(methyl methacrylate)/carbon nanotubes compositesYanhua Niu¹ and Guangxian Li²¹*College of Polymer Science and Engineering, Sichuan University, Chendu, China;* ²*College of Polymer Science and Engineering, Sichuan University, Chendu, China*

Poly(methyl methacrylate)/carbon nanotubes (PMMA/CNTs) composites with varying CNT concentration were prepared, in which the CNTs were physically modified by two kinds of ionic liquids (ILs) 1-butyl-3-methylimidazolium hexafluorophosphate ([BMIM][PF6]) and 1-hexyl-3-methylimidazolium hexafluorophosphate ([HMIM][PF6]), named B-CNTs and H-CNTs, respectively. The effect of ILs on the dispersion of CNTs and the rheological and electrical properties of PMMA/CNTs composites were investigated. It is demonstrated that the addition of ILs could significantly improve the CNTs dispersion in PMMA matrix, which as a result leads to the decrease of rheological percolation threshold and enhancement of the electrical conductivity of the composites. Compared with PMMA/B-CNTs, more homogeneous dispersion of CNTs, smaller rheological percolation threshold but higher threshold of electrical conductivity percolation could be found in PMMA/H-CNTs composites. The discrepancy between rheological and electrical conductivity percolation threshold could be on one hand ascribed to the stronger interaction between [HMIM][PF6] and CNTs than that of [BMIM][PF6] as evidenced by Fourier Transform Infrared (FTIR) results, and on the other hand might be due to the larger average radius of gyration of PMMA in [HMIM][PF6]. Thermal annealing could apparently facilitate the electrical conductivity of both PMMA/CNTs and PMMA/B-CNTs but it has no obvious effect on that of PMMA/H-CNTs composites.

Thursday 16:20 Nettuno 5-6

BE30

Rheology and morphology relationships of polyurethane modified bitumenRaissa Gallu*Ingénierie des matériaux polymères, Villeurbanne, France*

Bitumen materials are widely used for waterproofing and road pavement applications. Since more than 40 years, these ones are modified with polymers in order to increase their thermo-mechanical properties over a wide range of temperatures, i.e. to reduce rutting and cracking. Polymers commonly used to modify bitumen are thermoplastic elastomers such as poly(styrene-b-butadiene-

b-styrene) block copolymers (SBS) due to their good compatibility with bitumen and specific interactions with the different chemical species (SARA fractions - Saturated, Aliphatic, Resins, and Asphaltenes -). Nevertheless, SBS polymers display poor resistance to UV and therefore give poor aging resistance to the polymer-modified bitumen materials. To overcome these drawbacks, thermoplastic polyurethanes (TPU) are considered in the present study due to their improved durability and better resistance to UV compared to SBS. The work aims to study the relationships between the physico-chemical interactions between the TPU and the bitumen fractions, multi-scale microstructures, and rheological properties in TPU/bitumen blends, from rheological and surface tension measurements, fluorescence microscopy, and transmission (TEM), and scanning electron microscopies (SEM). Thus, several parameters were considered, such as the amount of TPU and the bitumen composition, i.e. bitumen differing from their SARA fractions (50/70 and 160/220 grades). In order to describe G' dependence with TPU content of the blends, the Takayanagi's model which considers a percolation threshold is used. As the model fits rheology results for the 160/220 bitumen-based blends, one can conclude that the compositions of the two co-existing phases remain the same whatever the TPU content. A different behavior could be evidenced for 50/70 bitumen-based blends. This study demonstrates that rheology is a powerful technique for investigating the interactions between SARA fractions of bitumen with polymer chains in polymer-modified bitumen blends.

Thursday 16:40 Nettuno 5-6

BE31

Effect of graphene on the rheological behavior of linear low density polyethylene/ethylene vinyl acetate co-continuous blends

Emna Helal¹, Rafael S. Kurusu¹, Nima Moghimian², Natassia L. Batista³, Pascal Hubert³, Eric David¹, and Nicole R. Demarquette¹

¹Mechanical Engineering Department, École de Technologie Supérieure, Montréal, Québec, Canada; ²NanoXplore, Montréal, Québec, Canada; ³Mechanical Engineering Department, McGill University, Montréal, Québec, Canada

Recently, co-continuous polymer blends have been widely investigated as templates to tailor the dispersion of nanoparticles such as carbon nanotubes (CNT) and graphene (GN) in order to obtain conductive composites with low percolation threshold. This objective is achieved by localizing the particles at the blend's interface and/or in one of the phases to facilitate the formation of networks. Such morphologies feature complex rheological behavior that is affected by the polymer components of the blend, the blend's interface and especially the particles located at the interface. In this study, co-continuous blends of linear low density polyethylene (LLDPE) and ethylene vinyl acetate (EVA) containing different concentrations of industrial grade GN (V20 from NanoXplore) have been investigated. The LLDPE/EVA/GN composites were prepared by a melt compounding technique. The linear viscoelastic properties were characterized by means of small amplitude oscillatory shear tests. Furthermore, time sweep tests were carried out to evaluate the effect of thermal annealing on the rheological response of the composites. All the composites exhibited an increase of their dynamic storage moduli (G') and reduced dependence on the angular frequency (ω) with increasing GN loading. At low frequencies, a plateau was observed in G' vs. ω plots of the blends containing GN contents higher than 1 wt%, indicating the formation of GN networks at loadings remarkably lower than what was observed for unblended LLDPE and EVA resins. In addition, when the composites were annealed at processing temperature, their storage moduli increased with annealing time. This increase of the elastic behavior was more pronounced in the case of composites slightly below the percolation threshold. This behavior was attributed to the evolution of blend's morphology and migration of GN particles to the interface. Finally, a correlation between rheological properties and characteristic domain size of the composites co-continuous morphologies was established.

Thursday 17:00 Nettuno 5-6

BE32

Self-assembly of nanoparticles in immiscible polymer blends

Giovanni Filippone, Rosaria Altobelli, and Martina Salzano de Luna

Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

Co-continuous polymer blends exhibit a series of intriguing properties which arise from the mutual interpenetration of the phases. This explains the considerable attention that this class of materials has received in the last years. On the other hand, the continuity of polymer phases and polymer-polymer interface makes this class of materials interesting systems for studying the self-assembly of nanoparticles in case of uneven distribution in the host medium due to the presence of a preferred phase/interface. Such a situation is rather common in many industrially relevant systems, where multiphase polymer systems are filled with solid particulate used as functional or structural filler. In this study we report an investigation on the structures in which plate-like nanoparticles (organoclay) self-assemble in a polystyrene/poly(methyl methacrylate) co-continuous blend. In particular, different nanoparticle networks build up depending on whether the filler enriches either of the phases or the polymer-polymer interface. The elastic features and stress-bearing ability of such structures are studied in detail through an original rheological approach, which enables us to isolate the elastic contribution of the filler network. The effect of the phase/interface preferred is highlighted by means of comparative analysis with systems based on the same polymers and nanoparticles, but in which the matrix is either a pure polymer or a blend with drop-in-matrix morphology. Significant differences emerge among the various systems in terms of filler percolation threshold and elastic features of the filler network, whose structure can be controlled by using the preferred polymer/interface as a template.

Thursday 17:20 Nettuno 5-6

BE33

Constitutive modelling of dispersive polymer blends

Wing-Hin B. Wong, Martien A. Hulsen, and Patrick D. Anderson

Eindhoven University of Technology, Eindhoven, The Netherlands

A well-known method for creating polymer materials with specific material properties is the blending of multiple existing polymers. However, many polymers are thermodynamically immiscible, so these tend to phase separate when mixed. For relatively small volume fractions, droplets of one polymer phase disperse through a matrix of the other polymer phase. During processing, these droplets can undergo morphological state transitions under the influence of the local flow field. Filament stretching, filament breakup, necking and coalescence are considered. The aim of this study is to develop a constitutive model (extending up on [1]) and

to cast this in a finite element framework. As the number of droplets in realistic conditions is extremely large, it is computationally intractable to model all droplets individually. Therefore, these are modelled as droplet populations that have macroscopically averaged morphological properties. These properties are the droplet stretch ratio, the unstretched droplet radius, the orientation vector and the number of droplets. The evolution equations of these properties vary based on the morphological state transitions. The current model describes the morphology evolution in arbitrary geometries, assuming Newtonian mixture constituents and monodisperse droplet populations. The numerical model has been validated for simple shear flow. Results have been obtained for Poiseuille flow and flow around a cylinder in a channel.

[1] Peters, G. W. et al. (2001). *Journal of Rheology*, 45(3), 659-689.

Thursday 17:40 Nettuno 5-6

BE34

Multilamellar vesicles morphology under flow

Angelo Pommella, Dario Donnarumma, Sergio Caserta, and Stefano Guido

Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

Surfactant solutions in several concentration ranges, common in a large number of industrial applications, show multilamellar vesicles (MLVs) morphology. In this work, we present an experimental investigation of the morphology evolution under flow of concentrated aqueous solution of linear alkylbenzene sulfonic acid (HLAS), characterized by MLVs dispersed in an isotropic micellar phase. The fluid is shear thinning, with a power law index dependent on the shear rate. Pressure-driven flow of the HLAS solution in glass micro-capillaries is investigated using high-speed video microscopy and image analysis. The velocity profiles show a flow-focusing effect of the lamellar phase in the central core of the capillary. The behavior in flow of MLVs can be described in analogy with that of unilamellar vesicles and emulsion droplets [1]. The results of this work can provide support for the processing of surfactant-based systems, such as cosmetic formulations, detergents, and food products.

[1] Pommella, A. et al. (2017). *Soft matter*, 13(37), 6304-6313.

Friday Morning

Symposium PL

Plenary Lectures

Friday 9:00 Sirene

PL3

Mechanical phase transitions and the rheology of stiff polymers

Fred C. MacKintosh

Department of Chemical & Biomolecular Engineering and Cente, Rice University, Houston, TX, United States

The mechanics of cells and tissues are largely governed by scaffolds of filamentous proteins that make up the cytoskeleton, as well as extracellular matrices. The observed rheology of these systems is particularly rich in their nonlinear response. The constituent biopolymers are typically much more rigid to bending than synthetic polymers, which tends to make the rheology of biopolymer networks more challenging and subtle to understand. As we argue, the rheology of stiff polymer networks can be partly understood in terms of mechanical phase transitions, especially in the limit of highly rigid, athermal fibers. A classic example of a mechanical phase transition was identified by Maxwell for macroscopic engineering structures: networks of struts or springs exhibit a continuous, second-order phase transition at the isostatic point, where the number of constraints imposed by connectivity just equals the number of mechanical degrees of freedom. We will present recent theoretical predictions and experimental evidence for mechanical phase transitions and critical phenomena in biopolymer networks. We demonstrate quantitative agreement between predicted nonlinear rheology and the measured elastic response of collagen networks. We also show how critical fluctuations associated with a mechanical phase transition can lead to strong anomalies in the normal stress of such systems.

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Friday 10:00 Sirene

CS36

Multi-responsive soft microgels: phase behaviour and rheology

R. Angelini¹, V. Nigro², B. Ruzicka¹, and E. Zaccarelli¹

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Phase behaviour and rheological properties of dispersions of a thermo- and pH-sensitive microgel composed of Interpenetrated Polymer Network (IPN) of poly(N-isopropylacrylamide) (PNIPAM) and poly(acrylic acid) (PAAc) have been investigated. These deformable colloidal particles offer the possibility to control particle softness by changing pH, temperature and PAAc content. Combining different experimental techniques, such as Dynamic Light Scattering (DLS), Differential Scanning Calorimetry (DSC), Small-Angle Neutron Scattering (SANS), Small-Angle X-ray Scattering (SAXS) and rheometry we find that microgels elasticity strongly depends on the topological inhomogeneities due to the crosslinking degree and on PNIPAM/PAAc ratio [1]. Moreover across the typical swollen-shrunk volume phase transition at T~305 K [2, 3] they show an ergodic to non-ergodic transition depending on concentration, pH and PAAc. The possibility to trigger a "strong-to-fragile" transition [4] by tuning the above parameters makes these soft colloidal suspensions good candidates to provide new insight into glass formation in molecular systems.

[1] Nigro, V. et al. (2015). The Journal of chemical physics, 143(11), 114904. [2] Nigro, V. et al. (2015). Journal of Non-Crystalline Solids, 407, 361-366. [3] Nigro, V. et al. (2017). Colloids and Surfaces A: Physicochemical and Engineering Aspects, 532, 389-396. [4] Nigro, V. et al. (2017). Soft matter, 13(30), 5185-5193.

Friday 10:20 Sirene

CS37

Rheology of hydrophobically modified soft colloids in water

Maddalena Mattiello and Michel Cloitre

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Soft colloids have attracted a lot of interest among the scientific community due to the appealing perspective of studying and modelling colloidal interaction on one hand, and the promising outlook of designing smart materials on the other. In both cases, the research efforts have focused on the development of colloidal materials that easy to synthesize, stimuli responsive and versatile in terms of applications. Here we present recent results on a new class of pH responsive soft colloidal particles - i.e. microgels, that can assemble through hydrophobic moieties covalently crosslinked at their surfaces, which are able interact through short range attractive forces in water. This system is thus a valuable candidate to explore the importance of interactions on the physics of jamming, when they are varied from soft repulsive to soft associative by tuning the architectural parameters of the particles (i.e. the crosslink density and the composition and architecture of the associative groups). Using linear viscoelasticity, non linear rheology, static and dynamic light scattering we establish the dynamical state diagram of these associative microgels. The comparison with purely repulsive

microgels with exactly the same composition, crosslink density, and particle size highlights the specificities of associative microgels. In the jammed glass regime, attractive interactions are responsible for flow heterogeneities - a competition between wall slip and/or shear-banding- controlled by the strength of the attractive interactions. We propose a two-state model involving two characteristic time scales, which are associated to the relaxation of in-cage associations and cage opening, respectively. Shear banding occurs when the shear rate exceeds the relaxation frequency of in-cage associations which is measured by linear rheology and is directly related to the characteristics of the hydrophobic groups. These results establish a link between the strength of short-range attractions and macroscopic flow instabilities.

Friday 10:40 Sirene

CS38

How artists achieved tempera paints? Rheology a key tool to understand heritage materials behavior

Guylaine Ducouret¹, Agathe Fanost², Maggy Jabert³, Laurence De Viguerie⁴, Philippe Walter⁵, Anne-Laure Rollet⁶, and Guillaume Mériquet⁷

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Since the ancient times, humans have developed painting techniques with various materials such as earth or ochre pigments to which wax, eggs, or collagen and gelatin (also called animal glues) can be added as binding agents. The tempera technique, which consists of mixing animal glue or eggs with pigments was widespread during the Middle Ages. At the end of the Renaissance, the tempera painting method was used again in order to formulate fast-drying media with paste-like consistency which adds glossier aspects to oil paintings. We wanted to find out the motivation and the benefits of this painting technique for the artists. The present study focuses on the rheological properties of model formulations based on old recipes found thanks to an extensive bibliography work. The studied pigments are green earths mostly composed of mica and smectite. Preliminary results show that macroscopic properties are correlated to the volume fraction of the pigments and their physico-chemical properties, which strongly depend on the grinding duration (15 min to 24h). The impact of the size and the shape of the mineral particles are also investigated. In parallel, the evolution of the morphological aspect of the pigments during the grinding operation was monitored by microscopy techniques (SEM, TEM and AFM) and X-ray diffraction (XRD). Moreover, the flow properties of the previous formulations modified by adding binders such as eggs and collagen are also studied. This work aims to understand the rheological properties of complex hybrid materials, i.e. paints based on green earth pigments, with respect to their architecture at the nano and microscale due to their distinctive physico-chemical properties and specific interactions in the presence of additives.

Friday 11:30 Sirene

Keynote CS39

Spontaneous stratification in drying films of small and large particles

Richard P. Sear

Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

Drying liquid films containing non-volatile components such as colloidal particles and polymers, have applications ranging from painting walls to the production of organic photovoltaic devices. Recently we [1] showed that during drying, mixtures of small and large particles could spontaneously segregate into a layer of the small particles on top of a layer of the larger particles. We observed this stratification in both experiment and computer simulation. This is a novel out-of-equilibrium self-organisation process. I will talk about this observation, and about our attempts to understand the mechanism. Drying creates gradients in the concentrations of the colloidal particles, and these gradients result in diffusiophoretic forces. By definition, a diffusiophoretic force is a force on particles of one species, due to a gradient in another species. Drying creates a gradient in the concentration of the smaller species and it is this gradient that drives motion of the larger particles deep into the film, creating stratification. Our earlier attempts to model this neglected flow of the solvent. I will talk about our more recent work [2], where we incorporate solvent flow, and show that it is crucial to accurately predicting stratification.

[1] Fortini, A. et al. (2016). Physical review letters, 116(11), 118301. [2] Sear, R. P., & Warren, P. B. (2017). Physical Review E, 96(6), 062602.

Friday 12:10 Sirene

CS40

Modeling a hydrodynamic instability in freely settling colloidal gels

Zsigmond Varga, Jennifer L. Hofmann, and James Swan

Department of Chemical Engineering, MIT, Cambridge, MA, United States

Attractive colloidal dispersions, suspensions of ne particles which aggregate and frequently form a space spanning elastic gel are ubiquitous materials used as thermal insulators, catalytic electrodes in fuel cells, and in many consumer care products and food stuffs. The colloidal networks in these materials can exist in a mode of free settling when the network weight exceeds its compressive yield stress. Subsequently, a hydrodynamic instability leading to loss of network integrity occurs. Recent observations using ghost particle velocimetry have shown that the loss of integrity is associated with the formation of eroded channels (so-called streamers) through which the fluid flows rapidly. In this talk, we present a phenomenological model that describes the radial growth of a streamer due to erosion of the network by rapid fluid back flow. The model exhibits a finite-time blow-up - the onset of catastrophic failure in the gel - due to activated breaking of the inter-colloid bonds, controlled by the relevant dimensionless groups describing the network: the ratio of buoyant forces to network strength, the particle volume fraction, and the strength of bonds relative to the thermal forces. To test the model, we use Brownian dynamics simulations of sedimenting and hydrodynamically interacting colloids in dilute colloidal gels and examine the initiation and propagation of this instability. The observed evolution of the network displays good agreement with the predicted dependence of the blow-up time on the physical properties of the network. Our findings confirm that the rate of collapse of the network is solely determined by the size of the streamer. The model dynamics are also shown to accurately replicate experimental measurements of streamer growth in two different gelling systems. Finally, we summarize our results in a stability-state diagram and formulate a criterion for collapse to guide engineering design of strong gels.

Friday 12:30 Sirene

CS41

A constitutive model for reversible structured materialsTainan G. Santos and Cezar O. Negrao*PPGEM, UTFPR, Curitiba, Parana 81280-340, Brazil*

Many fluids found in our daily lives and in industry are structured materials, such many foods, personal care products, paints, inks, cements, adhesives, greases, natural muds, drilling muds, crude oils, gels, and various slurries etc. The response of these fluids varies with time even for a constant imposed load. In the current work, a general model to predict the time dependent behaviour of structured fluids is proposed. Differently from previous models that are based on a structure parameter, the current model proposes kinetic equations for time-dependent properties that are derived from the equilibrium condition. This easy-to-understand and -to-fit model can be applied to either thixotropic or antithixotropic fluids. The structured materials dealt in this work are those in which an equilibrium is reached within an observable time after a constant load (stress or shear rate) is applied. A viscoelastic constitutive equation is used in step-up change simulations to exemplify the model potential. While the common stress overshoot is obtained in shear rate controlled experiment, the avalanche effect found in yield stress materials is noted in creep tests.

Symposium NF**Non Newtonian Fluid Mechanics & Flow Instabilities**

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Friday 10:00 Ulisse

Keynote NF36

Fracture propagation in polymeric transient networksSrishti Arora¹, Foyart Guillaume¹, Ole Hassager², Serge Mora³, Laurence Ramos¹, Amir Shabbir², and Christian Ligoure¹*¹Laboratoire Charles Coulomb, University of Montpellier, Montpellier, France; ²Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kongens Lyngby, Denmark; ³Laboratoire de Mécanique et de Génie Civil, University of Montpellier, Montpellier, France*

We investigate the fracture nucleation and propagation of reversible double transient networks, constituted of water solutions of entangled surfactant wormlike micelles reversibly linked by various amounts of telechelic polymers thus producing transient double networks when the micelles are sufficiently long and entangled. Two different geometries of fracture are considered: (i) For a filament stretching geometry, we provide a state diagram that delineates the regime of fracture without necking of the filament from the regime where no fracture or break-up has been observed. We show that filaments fracture when stretched at a rate larger than the inverse of the slowest relaxation time of the networks. We quantitatively demonstrate that dissipation processes are not relevant in our experimental conditions and that, depending on the density of nodes in the networks, fracture occurs in the linear viscoelastic regime or in a nonlinear regime. In addition, analysis of the crack opening profiles indicates deviations from a parabolic shape close to the crack tip for weakly connected networks. We demonstrate a direct correlation between the amplitude of the deviation from the parabolic shape and the amount of nonlinear viscoelasticity. (ii) For a Hele-Shaw cell geometry based on the injection of a low viscosity fluid into the viscoelastic material confined between two plates, we show that cracks nucleate when the sample deformation rate involved is comparable to the inverse of the shortest relaxation time scale of the networks. For a double network, significant rearrangements of the micelles occur as a crack nucleates and propagates. We show that birefringence develops at the crack tip over a finite length, λ , which corresponds to the length scale over which micelle alignment occurs. We find that λ is larger for slower cracks, suggesting an increase of ductility.

Friday 10:40 Ulisse

NF37

Periodic oscillations in shearing complex liquidsIvan Y. Skvortsov, Alexander Y. Malkin, and Valery G. Kulichikhin*Polymers rheology, A. V. Topchiev Institute of Petrochemical Synthesis, RAS, Moscow, Russia*

The appearance of self-oscillations in the shear flows of polymeric and colloidal systems is a well-known and repeatedly documented phenomenon. The results of these observations have been discussed on the base of different approaches and explained to various reasons and mechanisms. Basic possible cases of oscillation behavior and their primary classification will be considered in this presentation. Examination of very different fluids in rotational flow has shown that at least three types of oscillations can be observed in experiments of different modes. The first one proceeds at low shear stresses in standard rheometers. They can appear due to peculiarities in the software governing the regime of deformations or feedback in the driving or measuring system. They arise at a level of stresses about 0.1 Pa, and this means that it is necessary to treat corresponding data on viscosity and yield stress with a great caution. The second type of oscillation is associated with stick-slip transitions (the surface effect) and takes place at relatively high shear rates for different samples, and in particular for gel-like systems. The third type of oscillation appears as the result of bulk bifurcation and transitions between several possible structural states of the system under consideration.

Friday 11:30 Ulisse

NF38

Coiling instabilities for a power-law fluid: experimental and numerical comparison to the Newtonian case

Anselmo S. Pereira, Romain Castellani, Elie Hachem, and Rudy Valette*MINES ParisTech - CEMEF, PSL Research University, Sophia Antipolis 06904, France*

When a jet of fluid impacts a surface, coiling instabilities may occur depending on the balance between inertia, viscous and gravitational forces. Such instabilities can have a great influence on filling processes as they affect the structuration of the material and lead to inhomogeneity in the bulk (air entrapping or inhomogeneous concentrations). Depending on the velocity and the diameter of the jet, coiling frequencies and dimensions can be accurately predicted, at least in the case of a Newtonian fluid. A dimensional analysis of the phenomenon highlights different regimes depending on the balance of the playing forces in the system. In this communication, we study inertia driven coiling instabilities in non-Newtonian fluids such as dense suspensions. Numerically, we approximate their behaviour using power laws, valid at least locally. Direct numerical simulations are performed for the shear-thinning and shear-thickening cases and compared to what is found for Newtonian simulations and experiments. Coiling frequencies and diameters are indeed different and local parameters such as viscosity or shear rates inside the coil can be extracted. In parallel, experiments using dense suspensions are performed. Thanks to a high-speed camera, we observe that hardening (resp. softening) behaviour increases (resp. decreases) coils diameter and coiling period. We then demonstrate theoretically that the coiling instability in the inertial regime show characteristics (radius, frequency) than can be generalized for any power-law exponent.

Friday 11:50 Ulisse

NF39

Taylor-Couette flow of a shear-thinning fluid

Cherif Nouar¹ and Didier Bernardin²¹LEMMA, nancy, France; ²UMR 7563 CNRS University bde Lorraine, LEMTA, Vandoeuvre, France 54504, France

The present work deals with the influence of shear-thinning effects of a non-Newtonian fluid between two coaxial cylinders, on the Taylor-Couette flow structure. The inner cylinder is rotating and the outer one is at rest. The shear-thinning behaviour is described by the Carreau model. In a dimensionless form, the viscosity depends not only on the dimensionless shear-rate but also on the Reynolds number. In a first step, a linear stability analysis of the circular-Couette flow of Carreau-fluid is performed. Critical Reynolds and wave-numbers are determined for a large range of rheological parameters and for a wide (radius ratio =0.4) and a narrow gaps (radius ratio =0.9). With increasing shear-thinning effects, the vortices are squeezed against the inner cylinder because of the viscosity stratification in the base flow, i.e., the viscosity increases strongly from the inner to the outer cylinder. Furthermore, the characteristic time for the instability to grow, increases significantly with increasing shear-thinning effects. In the vicinity of the critical conditions, the Taylor vortex flow is studied using a weakly nonlinear analysis based on amplitude expansion method up to seventh-order. It is shown that the kinetic energy of the secondary flow is mainly concentrated on the azimuthal component of the velocity and decreases with increasing shear-thinning effects. In addition, a periodic axial stratification of the viscosity, induced by the vortices, takes place. It is significant for a wide gap and large shear-thinning effects. These results are confirmed using Lyapounov-Schmidt reduction model in the analysis of bifurcation branches. This axial stratification of the viscosity is probably at the origin of the destabilisation of the Taylor vortex flow that we have observed experimentally. The clarification of the mechanism by which the Taylor vortex flow loses its stability is under study.

Friday 12:10 Ulisse

NF40

THERMODYNAMIC INSTABILITY OF POLYMERIC LIQUIDS IN LARGE-AMPLITUDE OSCILLATORY SHEAR FLOW

Chaimongkol Saengow and Jeffrey Giacomin*Chemical Engineering Department, Queen's University, Kingston, Canada*

When polymeric liquids are subjected to oscillatory shear flow, if the amplitude of the shear rate is high enough, the shear stress response will not be periodic. In this work, we examine two thermodynamic instability criteria that have been suggested for large-amplitude oscillatory shear flow (LAOS). One of these criteria is based on non-equilibrium thermodynamics (the Ziegler criterion), and the other, on equilibrium thermodynamics (the free energy criterion). We evaluate these criteria for the simplest relevant constitutive model, the corotational Maxwell fluid. By relevant, we mean a model that at least predicts higher harmonics in LAOS.

Friday 12:30 Ulisse

NF41

Channel flow instabilities in shear-thinning viscoelastic fluids

Hugo A. Castillo Sanchez and Helen J. Wilson*Mathematics Department, University College London, London, London WC1E 6BT, United Kingdom*

Highly shear-thinning polymer solutions are now known to exhibit a linear, or supercritical, instability in channel flow. In previous work we had demonstrated that this instability could to some extent be modelled using a modified White-Metzner model; and that the mechanism relies critically on the viscoelasticity (as well as the shear-thinning nature) of the fluid. In the current work we extend our analysis to more realistic constitutive models. We demonstrate that we can now reproduce sinuous-mode instabilities (previously a discrepancy between theory and experiment) and explore the important of structure creation and deformation on the instability mechanism.

Symposium SM

Polymer Solutions & Melts

Organizers: Yuichi Masubuchi, Angel Moreno and Daniel Read

Friday 10:00 Tritone

SM31

Viscoelastic properties of semiflexible polymer solutions

Tadashi Inoue

Graduate School of Science, Osaka University, Toyonaka, Osaka 5600043, Japan

The complex modulus of cellulose triphenylcarbamate in tricesyl phosphate solutions was measured from the terminal flow to the glassy region in the range of concentration covering from dilute to the tightly entangled regime to clarify the viscoelastic properties of semiflexible polymer solutions. The complex strain-optical coefficient, which is the complex ratio of strain-induced birefringence to the strain, was simultaneously measured to evaluate the reorientation mode. In all the concentration regime, the stress-optical rule holds only in the terminal region, indicating that the significant contribution of bending and stretching modes in the higher frequency regions in addition of the reorientational mode, which is characteristic and dominant for flexible polymers. The exponent for high-frequency stress relaxation was found to be close to 3/5 irrespective of concentration, which is slightly smaller than the theoretical value for the worm-like chain, 3/4.

Friday 10:20 Tritone

SM32

Dynamics of semiflexible polymer solutions in the tightly entangled concentration regime: the fall of a theoretical framework

Manlio Tassieri

Biomedical Engineering, University of Glasgow, Glasgow, United Kingdom

I corroborate an important experimental evidence reported by Schuldt *et al.* [1] revealing the incapability of the current theoretical framework to fully describe the dynamics of semiflexible polymer solutions in the tightly entangled concentration regime. These results have been endorsed here by means of previously published, but overlooked, data by Tassieri *et al.* [2, 3]. The ensemble of information provides a strong evidence that the scaling law of the plateau modulus as a function of polymer's concentration and persistence length, i.e. $G_0 \propto c^\alpha Lp^\beta$, should have both the exponents positive, in contrast with all the existing predictions converging on similar values of $\alpha > 0$ and $\beta < 0$; hence the need of new theoretical models able to better interpret the contribution of the polymer bending rigidity to the viscoelastic properties of the polymer network. This work has been published in [4].

[1] Schuldt, C. *et al.* (2016). Physical review letters, 117(19), 197801. [2] Tassieri, M. *et al.* (2008). Physical review letters, 101(19), 198301. [3] Tassieri, M. *et al.* (2008). Biophysical journal, 94(6), 2170-2178. [4] Tassieri, M. (2017). Macromolecules, 50(14), 5611-5618.

Friday 10:40 Tritone

SM33

Rheology of polyvinyl alcohol in semi-diluted water solution

Annalisa Bellissimo¹, Finizia Auriemma¹, Andrea Gabriele², Rossana Pasquino³, Nino Grizzuti³, and Claudio De Rosa¹

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Polyvinyl alcohol (PVA) is a hydrophilic and biocompatible polymer with excellent film forming properties. As a water-soluble synthetic polymer has found a significant role in many industrial applications including medical patches, artificial skin, coatings, emulsifier and adhesive. In all these applications PVA is found in solution with solvents that act as plasticizers. Their role is to modify the chain entanglement of PVA, hence PVA is often found as a semi-diluted polymer solution. Therefore, the rheology of PVA-water solutions is studied to obtain information about the mobility of PVA, essential for a good interpenetration of grafting and, casting to the adhesion process. The longest relaxation time of PVA chains, indicative of the mobility of the chains, is evaluated through measurements of viscous (G'') and elastic modulus (G') in typical rheological experiments. The effect of the molecular mass of the PVA and of the concentration of the polymer solution on the longest relaxation time of PVA are analyzed. For the first time, we are complementing the Mechanical Rheology with the Diffusing Wave Spectroscopy (DWS). DWS is used to obtain information in a wider spectrum of frequencies, in particular in the high frequency regime, which is prohibitive with a rotational rheometer. This work has allowed understanding at molecular level diffusive phenomena at the interface of PVA clarifying how the properties and the nature of the polymer/solvent affect the mobility of the chains.

Friday 11:30 Tritone

SM34

Interactions between rigid rod polysaccharide solutions and saliva

Xinxin Li¹, Stephen E. Harding², and Bettina Wolf¹

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Although polysaccharides are widely applied in foods, there is little knowledge of the interactions between saliva and polysaccharide solutions. Food stuff is diluted with saliva and while being processed by interactions between teeth, tongue and palate into a food bolus ready for swallowing, which experiences mixed flow fields with shear and elongational components. In this project we are asking the question whether dilution with saliva, as opposed to water, changes shear or extensional flow properties. This is relevant

to people who have swallowing disorders. Choi et al. [1] demonstrated that the filament break-up time of xanthan gum (rigid rod) solution mixed with saliva was prolonged compared to mixing with water. The aim of this present research is to validate the observed rigid rod molecule behaviour by investigating another rigid rod molecule scleroglucan. Unlike negatively charged xanthan gum, scleroglucan is uncharged. It was further hypothesised that the results can be reproduced with reconstituted saliva, circumventing the impact of deterioration of saliva properties. The rheological behaviour of scleroglucan solutions was analysed in shear, oscillatory shear and extensional flow to compare to xanthan gum. The behaviour of both biopolymers was very comparable: highly shear thinning, G' dominating G'' , overshoot in G'' at the end of the linear viscoelastic regime for solution concentration of 1%. Under extensional deformation, the break-up time for scleroglucan was significantly higher. The increase in capillary break-up time for xanthan gum upon mixing with saliva was confirmed and also observed for scleroglucan. Use of reconstituted saliva led to a less pronounced increase in break-up time for xanthan gum. It appears that this research has been able to validate the previously reported results [1]. To understand the differences, the macromolecular interactions will be assessed using the method of analytical ultracentrifugation.

[1] Choi, H. et al. (2014). *Food hydrocolloids*, 40, 71-75.

Friday 11:50 Tritone

SM35

Viscoelastic behaviour of aqueous solution of chemically modified cellulose ethers

Toshiyuki Shikata and Kengo Arai

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Many kinds of chemically modified celluloses have been supplied for applications. We pay attention to hydroxypropylated and methylated cellulose ethers (HpMCs) which possess high solubility in cold water such as at 10 °C, but lose it at higher temperatures than e.g. 50 °C. Here, we report linear viscoelastic behaviours of aqueous solutions of HpMCs and discuss the configuration of HpMC molecules in aqueous solution. Series of HpMC samples, which have the average substitution numbers of hydroxypropyl and methyl groups of 1.9 and 0.25, respectively, for 3 hydroxy groups in each glucose unit and have the weight average molecular weights: $M_w/1000=20, 75, 150, 215$ and 300, were dissolved into pure water over a wide concentration (c) range. Dynamic viscoelastic measurements were carried out for aqueous HpMC systems, and storage and loss moduli, G' and G'' , were determined in a frequency range: $\omega=0.01-100\text{ s}^{-1}$ at 10 °C. Although the viscoelasticity of the systems became pronounced with increasing concentrations and molecular weights as usually observed in polymeric solutions, the determined viscoelastic parameters did not show that HpMC molecules behave as flexible polymeric chains. The c and M_w dependencies for the average modulus ($1/J_e$: the reciprocal of steady state compliance) and relaxation time (t_w) for the system were described as $1/J_e \sim (c/M_w)^{1.3}$ and $t_w \sim c^{2.6} M_w^{5.4}$, and were rather different from that observed in entangling flexible polymer solutions; $1/J_e \sim c^2$ and $t_w \sim c^{3.5} M_w^{3.5}$ (for aqueous solution of flexible polysaccharide, Pullulan). However, the obtained relationship fairly corresponds to the theoretical prediction for rigid rodlike particles with length of L ; $1/J_e \sim (c/M_w)$ and $t_w \sim (c/M_w)^2 L^9$ ($\sim c^2 M_w^7$, when a simple relationship $L \sim M_w$ is assumed). Consequently, HpMCs do not behave as flexible polymer chains, but rigid rodlike particles in aqueous solution.

Friday 12:10 Tritone

SM36

Rheological and hydrodynamic properties of solutions of ternary copolymers based on acrylonitrile prepared by different synthetic procedures

Valery G. Kulichikhin¹, Elena V. Chernikova², and Ivan Y. Skvortsov¹

¹*Polymers rheology, A. V. Topchiev Institute of Petrochemical Synthesis, RAS, Moscow, Russia;* ²*High-Molecular Weight Compounds, M.V.Lomonosov Moscow State University, Moscow, Russia*

By means of classical and RAFT radical polymerization series of the ternary copolymers based on acrylonitrile, methylacrylate and itaconic acid with molecular weights of 70-200 kg/mole and polydispersity index ~ 2 were synthesized in dimethylsulfoxide solutions. It was analyzed an influence of synthetic procedure on rheological behavior of dilute and concentrated solutions. In the field of concentrated solutions the viscous and viscoelastic behavior at different temperatures was similar: non-Newtonian flow curves and moderate viscoelasticity. However, viscometry of the dilute solutions allowed us to identify some dissimilarities in interaction of solvent with macromolecules prepared with different methods. This distinction reflects on intrinsic viscosity as well as on Huggins and Martin constants. In addition, determined from concentration dependences of viscosity the crossover point "feels" features of macromolecular constitution. Presumably, the difference in behavior of the dilute solutions is stipulated with variation in branching and composition inhomogeneity, typical for ternary copolymers with rather different amounts of comonomers. In Martin equation coordinates the generalized curve was plotted for dilute solutions, but extension to more concentrated domain does not work. The transition to this domain requires entering the additional parameter that reflects the effective density of entanglements network, i.e., the ratio of current concentration over crossover point, C/C_c . This approach has allowed us to construct the generalized concentration dependence of viscosity for the whole concentration diapason. Reasons of variation of parameters described intensity of interaction of macromolecules with solvent are under consideration now.

Friday 12:30 Tritone

SM37

Redrawing the Viovy diagram for binary polymer blends

Daniel J. Read¹, Maksim E. Shivokhin², and Alexei E. Likhtman³

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We have performed simulations using the "slip-spring" model [1] to assess the relaxation behaviour of long chains subjected to different rates of constraint release (CR), and to combinations of fast and slow constraint release. These simulations allow us to probe (i) the relative rates of relaxation by reptation and by CR, both for dilute long chains and for long chains entangled with both short and long chains, and (ii) the effects of CR on contour length fluctuations. Making use of the results of these simulations, we revisit the classic diagram of Viovy et al. [2], in which the relaxation behaviour of binary blends is projected onto a two dimensional

map in the space of Graessley parameter versus number of slow entanglements along a long chain. We introduce the effect of contour length fluctuations into this map, giving new boundaries on the diagram, and quantitatively reposition the existing boundaries in the light of numerical data from the slip-spring simulations. Of particular interest is a region in which CLF along the fat tube can accelerate terminal relaxation, even when the fastest chain reptation is along the thin tube. We demonstrate that the relaxation behaviour of a wide variety of literature binary blends, both in the dilute and non-dilute regime, and for a huge range of the Graessley parameter, can be successfully mapped onto our redrawn diagram.

[1] Likhtman, A. E. (2005). *Macromolecules*, 38(14), 6128-6139. [2] Viovy, J. L. et al. (1991). *Macromolecules*, 24(12), 3587-3596.

Symposium FP

Food, Pharmaceuticals & Cosmetics

Organizers: Bruno de Cindio, Pietro Matricardi and Mats Stading

Friday 10:00 Nettuno 1

FP10

Nano-rheometry for food oral processing

Mats Stading¹, Patricia Lopez-Sanchez¹, Berta Marco¹, Thana Sriviriyakul², Sara Bogren², and Christer Johansson²

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The complete chewing and swallowing process is an intricate combination of voluntary and involuntary actions and it involves complex flow geometry as well as a mixture of shear and extensional flow during which aroma and taste is perceived. We seldom register the process, but during these seconds of complex processes we form our complete opinion of the food we eat. We would ideally want to study textural changes, wetting, mass transport etc. directly in the mouth, but this generally means experimental equipment interfering with the oral processing mechanisms, and altering perception of the food. By using magnetic nanoparticles (MNP) local properties are possible to sense remotely by measuring and analyzing the magnetic response from the magnetic particles. This means that rheological properties, texture and aggregation could be followed remotely and non-invasively. By using sensitive magnetic techniques the stochastic Brownian rotation of functionalized MNPs can be determined, thus giving local aggregation and local viscoelastic properties i.e. nano-rheology. This can in turn give a measure of changes in texture (softening, drying, aggregation, dissolution) and mouth feel (viscosity). Fluids with increasing rheological complexity have been characterized by nano-rheology and small amplitude oscillatory shear techniques. The fluids range from water, through PEG to xanthan and gelling alginate, and the results show good correspondence for the simpler fluids whereas fluid and gel microstructure has to be taken into account for the gelling systems.

Friday 10:20 Nettuno 1

FP11

Understanding starch swelling behavior and how it impacts rheology and functional properties of food systems

Leslie G. Howarth and Judith K. Whaley

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Starches are well-known thickening agents, and the complexities of such soft particle suspensions must be carefully considered during product development. Even in simple systems, textural properties can vary in surprising ways as the swelling of the starch and concentration-in-use change. Physical and chemical treatments are applied to starch to control the swelling, as the swelling is reduced the particles become more rigid which gives them tolerance to shear which occurs during food processing. In the current work, we have modelled the effects of swelling volume and concentration on viscous and elastic properties. This has allowed us to create texture maps for thickened starch systems. We have been able to overlay the texture maps, generated from instrument data, with sensory data to create comprehensive texture maps for starch dispersions having high predictive power for the effects of starch swelling, concentration and processing upon the textural and sensory attributes of the resulting food products.

Friday 10:40 Nettuno 1

FP12

How do pH and acid anion affect thermal gelation of egg yolk?

José M. Aguilar, Carlos Bengoechea, Felipe Cordobes, and Antonio Guerrero

Chemical Engineering, Universidad de Sevilla, Sevilla, Sevilla 41012, Spain

Egg yolk is a well-known multifunctional ingredient in many food applications and consists of a complex association of lipids (33% by weight), proteins (17%) and water (50%). Native egg yolk hardly shows any deviation from the newtonian behaviour. However, egg yolk may undergo dramatic changes, when processed at high temperature, low pH or high hydrostatic pressure, turning into a gel with remarkable viscoelastic properties. Thus, rheology may be considered essential to control egg yolk processing at conditions that may involve any disturbance from its native state. The objective of this study was to assess the influence of reducing pH from its native value on the heat-induced gelation behaviour of egg yolk by monitoring its linear viscoelastic properties. Three acids differing in their location in the Hofmeister series were used (Phosphoric, Hydrochloric and Citric acids). The viscoelastic measurements were carried out using parallel plate geometry (ARES-LS1 and AR-2000, TA Instruments), by means of: (i) stress sweep tests to delimit the linear viscoelastic range at different temperatures; (ii) temperature ramp tests to record the changes during egg yolk protein gelation; and (iii) frequency sweep tests at 20°C, before and after the thermal cycle. The microstructure of gels was also evaluated by Cryo-scanning Electronic Microscopy (CryoSEM). Gelation of egg yolk follows a typical pattern showing four different regions: (i) a fluid-like region (ii) a sol-gel transition region involving denaturation, aggregation of protein molecules and association of aggregates to form a gel network; (iii) a plateau region for G' and G'' and (iv) a reinforcement of the gel network

through the rebuilding of physical interactions during cooling. This pattern may be modified to a great extent, depending on pH and the acid anion involved. Although the viscoelastic properties of the final gels were similar, large differences in gel microstructure were found depending on the acid anion used.

Friday 11:30 Nettuno 1

FP13

Investigation of the rheological behavior of blended dough systems: examining the interplay between wheat and rye flour

Yannick Meeus¹, Frederik Janssen², Jan Delcour², and Paula Moldenaers¹

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In this work, the rheological behavior of doughs with a targeted high breadmaking potential and improved nutritional profile was investigated using dough blends of wheat and rye flour. In addition, wheat flour was diluted with starch to gain insight in the effect of a pure decrease in wheat gluten content and the resulting changes in rheological behavior. Small amplitude oscillatory shear measurements characterized the dough in the linear regime, whereas uniaxial extensional measurements were used to investigate the non-linear rheological behavior. With increasing percentage of rye flour in the blend, the doughs became stiffer, which was displayed by an increase of the dynamic moduli in the oscillatory measurements. Likewise, in the extensional tests the linear viscoelastic envelope shifted upwards with increasing rye content. The extensional tests also showed that the transient extensional viscosity at maximum strain did not decrease as wheat flour was systematically replaced by rye flour. Nevertheless, even a dough blend consisting of 60% rye and only 40% wheat produced strain hardening behavior. Contrary to this, it was found that as wheat was systematically replaced by pure starch, the transient extensional viscosity at maximum strain did decrease. The obtained results show the usefulness of uniaxial extensional measurements in evaluating the rheological behavior of blended dough systems with non-wheat grains. In addition, the study clearly shows that in dough blends with non-wheat grains, expected changes in the rheological behavior caused by a decrease in the wheat gluten content can be compensated for by other dough components, one possibility being the arabinoxylan fraction. This important observation can aid in the development of nutritious breads of higher quality.

Friday 11:50 Nettuno 1

FP14

Fractional constitutive modelling of the linear and non-linear behaviour of wheat flour dough

Mathieu Meerts¹, Bavand Keshavarz², Ruth Cardinaels³, Christophe M. Courtin⁴, Paula Moldenaers¹, and Gareth H. McKinley²

¹*Chemical Engineering, KU Leuven, Leuven, Belgium;* ²*Mechanical Engineering, MIT, Cambridge, MA, United States;* ³*Mechanical Engineering, TU Eindhoven, Eindhoven, The Netherlands;* ⁴*Microbial and Molecular Systems, KU Leuven, Leuven, Belgium*

Wheat flour dough consists of a gluten matrix, in which starch granules are dispersed as well as many other minor components. The rheological properties of dough are known to be linked to the final quality of the baked product. A general modelling framework that enables description and prediction of dough rheology under different conditions is thus highly desirable. In view of the broad relaxation spectrum of dough, 'traditional' constitutive models (such as the generalised Maxwell model which uses a discrete spectrum of relaxation times) are highly impractical requiring extensive sets of parameters. Alternatively, the critical gel model, which is based on a power law relaxation function, is often used because of its simplicity. The frequency dependence of the moduli can be captured quite well with only two parameters, but the applicability of the critical gel model is fairly limited when probing very long timescales or non-linear deformations. To describe materials with complex multiscale microstructures, fractional constitutive equations (FCEs) offer a compact mathematical framework. The resulting constitutive parameters are quasi-properties, intermediate between a shear modulus and a viscosity. They provide a measure of the dynamic processes within a material rather than the equilibrium state. For dough, the fractional Maxwell model (FMM) was found to yield a very accurate description of all linear material functions, while requiring only four parameters. Although FCEs were originally developed for modelling the linear behaviour of complex materials, these models can be extended to cover the non-linear region as well. We show that dough exhibits time-strain separability, and the kernel function in the K-BKZ equation can be split into a memory function and a non-linear strain energy function. By combining a fractional description of the memory function with an appropriate choice of the damping function, we were able to capture the rheological behaviour of dough in both non-linear shear and extension quite well.

Friday 12:10 Nettuno 1

FP15

Yoghurt as a nutritional ingredient in bakery foods Impact on rheology characteristics of the wheat bread dough

Carla A. Graça, Anabela C. Raymundo, and Isabel M. Sousa

LEAF-Linking Landscape, Environment, Agriculture and Food, University of Lisbon - Instituto Superior de Agronomia, Lisbon, Portugal

Bakery industry is moving towards the development of healthy foods, attractive, and convenient, corresponding to an increasingly demanding consumer. The incorporation of ingredients that exhibit functional and health-enhancing properties, in addition to traditional nutrients, are an interesting alternative for the development of innovative products with impact on the new niches of the healthy food market. Dairy products, such as yogurt, could be an interesting alternative to design nutritional added-value foods, since it is a source of proteins, vitamins (such as A and B12) and minerals (like calcium). Gluten is the main structure-forming protein in dough and is responsible for the good bread-making properties of wheat flour. Increasing the levels of proteins by yogurt addition can impact the structure of the final products. The presence of lactic acid bacteria (LAB) from the yoghurt produces lactic acid, lowering the pH below 5, and the interaction between yeast and LAB can promote changes on wheat dough during fermentation. These interactions can change bread characteristics. The study of dough rheological properties is useful to measure these changes and predict the quality attributes of the end product. In this work, the impact of the yoghurt addition (3% up to 40% w/w) on the rheological features of the wheat dough was studied. Rheological parameters were measured under small amplitude oscillatory shear

(SAOS) to evaluate changings on the viscoelastic properties (G' and G''), of the doughs with different levels of yoghurt. The dough extensibility was assessed by uniaxial extension tests, under 30', 60' and 90' of dough resting time, using a texture analyser equipped with an SMS-Kieffer Dough and Gluten Extensibility Rig. In general, the yoghurt addition promoted a reinforcement of the dough structure, expressed in terms of the elastic moduli. Extensibility tests supported this feature, as well as the impact on bread structure evaluated accessed by texture measurements in puncture tests.

Friday 12:30 Nettuno 1

FP16

Aging and rheology of gluten doughs

Salvatore Costanzo¹, Marie H       Morel², Amelie Banc¹, and Laurence Ramos¹

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Gluten, the protein-rich fraction of wheat, is responsible for the elasticity of doughs, a fundamental characteristic for the bread-making process. Gluten can be extracted from native wheat by washing the dough to remove starch, cell-wall material and other soluble components. The result is a mixture of two types of proteins, gliadins and glutenins. Gliadins are alcohol-soluble monomeric proteins while glutenins are polymeric, as they are formed by glutenin subunits linked via disulphide bonds. During the kneading process, gluten proteins are thought to associate themselves into a hydrated network through hydrogen bonding. Recently, some of the authors have developed a protocol to separate a fraction of the native gluten, hereafter called "model gluten", containing a 50/50 content of gliadin and glutenin, but with a relatively low content of high molecular weight glutenin, thus resulting completely soluble in a food grade solvent (50/50 v/v water/ethanol) [1, 2]. From a processing perspective, it is important to understand the role of gluten composition, quantity of water and mixing time, as those parameters are known to strongly affect the viscoelastic properties of the final product, hence its quality [3]. In this optics, we perform a comparative study on the rheological properties of native and model glutes, dispersed both in pure water and in water/ethanol mixtures. Since the extraction process produces very small quantities of model gluten, we have developed a gram-scale mixograph to standardize the mixing process during the preparation of the samples. The standardization of the sample preparation together with the control of the sample composition and solvent-mediated interactions allows for a rationale study of the rheology of gluten.

[1] Dahesh, M. et al. (2014). The Journal of Physical Chemistry B, 118(38), 11065-11076. [2] Dahesh, M. et al. (2016). Food Hydrocolloids, 52, 1-10. [3] Uthayakumaran, S. et al. (2002). Rheologica Acta, 41(1-2), 162-172.

Symposium IP

Industrial Rheology & Processing

Organizers: Paulo Roberto de Souza Mendes, Dino Ferri and Joao Maia

Friday 10:00 Nettuno 2-3

IP9

Stability analysis of isothermal and non-isothermal viscoelastic film casting processes

Changhoon Lee¹, Ilyoung Kwon², Hyun Wook Jung¹, and Jae Chun Hyun¹

¹Department of Chemical and Biological Engineering, Korea University, Seoul, Republic of Korea; ²Lg Hausys, Seoul, Republic of Korea

Film casting is one of the most commonly used extensional polymer processes, producing uniform polymer films. During this process, the film dimension is determined by cooling and extensional deformation behavior. Over a certain draw ratio, the periodic fluctuation of state variables, called draw resonance, inevitably occurs, deteriorating the film quality. The critical draw ratios at given processing conditions are closely dependent on thermal and viscoelastic properties of polymer. In this study, FEM-based simulations were performed for the stability analysis of two-dimensional (2D) viscoelastic film casting processes, combining the tension boundary condition and frequency response method. Phan-Thien and Tanner (PTT) fluid model which is capable of portraying extensional-thinning and extensional-thickening behaviors was incorporated. The critical onsets were determined with Nyquist plots of transfer function between take-up velocity output and tension input in frequency domain and transient responses in time domain. In addition, the effect of cooling condition on the stability was systematically scrutinized.

Friday 10:20 Nettuno 2-3

IP10

Computational modeling of the selective laser sintering process: viscoelastic flow

Caroline Balemans, Martien A. Hulsen, and Patrick D. Anderson

Eindhoven University of Technology, Eindhoven, The Netherlands

Selective laser sintering is a promising 3D printing technique. Products are built of locally heated polymer powder, on a layer-by-layer basis. To find the relation between the process and the mechanical properties of the printed products, we assess the sintering process in detail by numerical methods. We developed a computational model using the finite element method to solve the flow problem of the sintering mechanism of two viscoelastic particles. The flow is assumed to be isothermal, and the particles are assumed to be in a liquid state. We use both the Giesekus and the eXtended Pom-Pom [1] constitutive models to describe the flow behavior of the polymer. We will show the effect of the Deborah number and other dimensionless parameters present in the rheological models on the flow behavior of the system. In particular, the shape change and the conformation tensor are considered. The conformation tensor is a measure for the polymeric strain, and plays a significant role in the crystallization kinetics of semicrystalline polymers like polyamide 12, which is usually used in SLS.

[1] Verbeeten, W. M. et al. (2001). Journal of Rheology, 45(4), 823-843.

Friday 10:40 Nettuno 2-3

IP11

The structural and rheological properties of micelles in a shear flowBreannan O Conchuir¹, Richard L. Anderson², and Michael A. Johnston³¹IBM Research UK, Warrington, United Kingdom; ²STFC Hartree Centre, Warrington, United Kingdom; ³IBM Research Ireland, Dublin, Ireland

The viscosity of surfactant solutions is of vital interest to the industrial sector. However, the geometric and rheological properties of micellar suspensions remain poorly resolved, especially when the system is stressed by an external shearing force. As a result, companies are beginning to turn towards computer aided formulation to better understand and optimise the rheological properties of their products, from the tactile characteristics of personal-care products, to the action of engine lubricants. In this talk, we will present the results of our coarse-grained Dissipative Particle Dynamics (DPD) DL-MESO simulations of various industrial surfactant systems in shearing flows. These computations elucidate the delicate interplay between force field parameters, structures and rheology. The threefold relationship between a) surfactant interactions and concentration, b) micelle formation, size, shape and orientation, and c) system shearing stress, shear rate and viscosity, is extensively explored in this study. The calculations were performed on IBM power-based High Performance Computing (HPC) systems and the DPD force field interaction parameters were generated using automated optimization methods.

Friday 11:30 Nettuno 2-3

IP12

Rheological analysis to understand the mechanism of sewage sludge dewaterability

Jingsi Zhang and Zhuo Li

School of Environmental Science and Engineering, Tongji University, Shanghai, China

Large quantities of excess sludge are generated as a by-product of biological wastewater treatment processes. Sewage sludge behaves as non-Newtonian fluid, which is composed of inorganic and organic components. Anaerobic digestion, which can stabilize organic substances while simultaneously generating valuable energy resource, biogas, is a sustainable treatment technology for sewage sludge. The dewaterability of digestate needs to be improved to allow better-quality disposal, such as incineration and land use. Rheological characterization is not only a fundamental requirement for optimizing the sludge mixing and transport, but is a potential method for characterizing the sludge network structure and understanding the mechanisms of dewaterability evolution during anaerobic digestion. In this work, rheological characterization combined with the analysis of porous network structure compactness was applied to understand the mechanism of high-solids sludge dewaterability evolution during anaerobic digestion with or without thermal hydrolysis. The results show that smaller particle size and larger surface area of sludge were induced by thermal hydrolysis and anaerobic digestion treatments. The structure strength and compactness of sludge, represented by elastic modulus and fractal dimension respectively, decreased with increase of digestion time. The porous network structure was broken up by thermal hydrolysis pretreatment and was further weakened during anaerobic digestion, which correspondingly improved the dewaterability of digestates. The logarithm of elastic modulus increased linearly with fractal dimension regardless of the pretreatment. Both fractal dimension and elastic modulus showed linear relationship with dewaterability. The analysis method developed here was demonstrated to be applicable in quantitative evaluation of sludge dewaterability, which depended positively on both thermal hydrolysis and anaerobic digestion.

Friday 11:50 Nettuno 2-3

IP13

Anisotropic thermal transport in non-linear non-isothermal polymeric flows

David Nieto Simavilla and Wilco M. H. Verbeeten

SIRG Department of Civil Engineering, Universidad de Burgos, Burgos, Burgos 09006, Spain

Over the last decades, the use of finite elements methods to simulate the complex flows occurring in polymer manufacturing has grown considerably. However, while significant efforts have been dedicated to include more complete rheological constitutive models into these numeric packages, the study of the underlying phenomena and implementation of non-isothermal flows has been very limited. The degree of complexity of such calculations is caused by the addition to the problem of the energy equation, which is strongly coupled to the momentum balance because viscosity is highly dependent on temperature. To further complicate this scheme, the thermo-physical properties of polymeric materials are strongly influenced by the deformation-induced molecular orientation. As a result, thermal conductivity needs to be treated as an anisotropic tensor when polymers are subjected to deformation. Furthermore, a linear relationship between the thermal conductivity and stress tensors, known as the stress-thermal rule, has been found to be universal (i.e. independent of polymer chemistry). Our work takes advantage of this universality to combine the stress-thermal rule with two recent constitutive equations proposed for linear (Rolie Poly) and branched (eXtended Pom-Pom) polymers to obtain predictions for the anisotropy in thermal conductivity. We demonstrate how these two constitutive models provide accurate descriptions of the available non-linear rheology and thermal transport data, and venture predictions for a number of interesting flows. Remarkably, our approach allows implementation of anisotropy in thermal conductivity into finite elements simulations without adding any adjusting parameters to those of the viscoelastic model. We present this work as a first step towards a molecular-to-continuum methodology for the simulation of industrially relevant non-isothermal flows to predict not only the flow characteristics but also the final properties of the material after processing.

Friday 12:10 Nettuno 2-3

IP14

Exchange flow of yield stress materials in vertical tubesPriscilla R. Varges¹, Aline A. Abdu¹, Mônica F. Naccache¹, Paulo R. de Souza Mendes¹, Andre L. Martins², and Bruno S. Fonseca¹¹*Department of Mechanical Engineering, Pontificia Universidade Católica do Rio de Janeiro, RJ, RJ 22451900, Brazil;* ²*CENPES, Petrobras, Rio de Janeiro, RJ 21941915, Brazil*

In the process of oil well abandonment, a cement plug and/or a viscous pill is placed above the drilling fluid. The process is completed when the well is sealed after the cement cure. Since the drilling fluid is less dense than the cement or the viscous pill, their positions tend to invert leading to an unstable flow condition. This exchange flow is analyzed experimentally and numerically in this work. Flow visualization experiments are performed with a denser liquid positioned above a lower-density liquid in a Plexiglas vertical tube. The interface front speed is recorded with the aid of a digital camera, and measured through image processing and analysis. The experiments are performed using Carbopol[®] 980 aqueous solutions at different concentrations. The numerical solution is obtained using Fluent[®] software. The governing conservation equations are solved via the finite volume technique and the Volume of Fluid method. The role of density and viscosity differences, surface tension, yield stress and fluid elasticity is investigated. The effects of the governing parameters on the inversion velocity and flow regime are analyzed. Three different flow regimes are observed, namely unstable, quasi-stable, and stable (no flow). The unstable regime is a wavy core-annular flow with the denser liquid in the core. In the quasi-stable regime a slow plug flow begins after a time delay, due to thixotropic effects. The results obtained allow the identification of an operational window where the inversion velocity is sufficiently low (or zero) to ensure the success of the cement plug operation.

Friday 12:30 Nettuno 2-3

IP15

Gelation phenomena in polypropylene and polyethylene as caused by phase separation, nucleation or crystallizationMarkus Gahleitner¹, Jingbo Wang¹, Florian Prades¹, and Klaus Bernreithner²¹*LPPO SPPR, Borealis Polyolefine GmbH, Linz 4021, Austria;* ²*Innotech PM, Borealis Polyolefine GmbH, Linz 4021, Austria*

The use of rheological techniques for studying phase separation, nucleation and especially crystallization provides an additional technique for developing an improved understanding of processing phenomena of semicrystalline polymers. Temperature sweeps in the linear-viscoelastic domain have been established as a method for investigating gelation phenomena related to nucleation and crystallization behavior under quasi-quiescent conditions like in the works of Winter et al. In studying nucleation effects in polypropylene (PP) homopolymers and random copolymers by soluble nucleating agents of sorbitol- and trisamide-type by this technique, the fibril network formation before the actual PP crystallization can be observed. The stability of such networks is, however, limited and the orientation of the fibrils enhances flow-induced structure formation here as well. It has now been found that quite similar effects are found with phase separation of low molecular weight waxes in polyethylene (PE) plastomers (single-site catalyst based homogeneous very low density PE). Especially PE-waxes can cause network formation and gelation, resulting in similar structures as for HDPE crystallization from solutions. In contrast, PP waxes are found to be distributed as micro-droplets which solidify well above the matrix crystallization temperature. It can be shown that the final phase morphology correlates well to the thermo-rheological behavior.

Symposium LA**Living & Active Matter**

Organizers: Pietro Cicuta, Antonio De Simone and Gerhard Gompper

Friday 10:00 Nettuno 4

LA5

Biological and bio-inspired motility at microscopic scales: locomotion by shape controlAntonio De Simone and Giovanni Noselli*MathLab, SISSA, Trieste, Italy*

Locomotion strategies employed by unicellular organism are a rich source of inspiration for studying mechanisms for shape control. In fact, in an overwhelming majority of cases, biological locomotion can be described as the result of the body pushing against the world, by using shape change. Motion is then a result Newton's third and second law: the world reacts with a force that can be exploited by the body as a propulsive force, which puts the body into motion following the laws of mechanics. Strategies employed by unicellular organisms are particularly interesting because they are invisible to the naked eye, and offer surprising new solutions to the question of how shape can be controlled. Depending on the mechanisms for shape change available to the organism (or to the bio-inspired engineering device), and on the mechanical interactions with the environment (hydrodynamic interactions with a surrounding fluid, frictional interactions with a substrate, etc.), the problem gives rise to governing equations of different kinds. However, their general structure is similar, and an approach based on the tools of geometric control theory is often useful as a unifying tool. This study is often rewarding as it results in new concepts for the possibility of engineering new materials and structures with controllable shape, such as "morphing by modulating surface shears". This is the template employed by Euglena for its amoeboid motion, also known as metaboly. In recent years, we have studied locomotion by shape control using a variety of methods: modelling, theory, and numerical simulation, observations at the microscope, manufacturing of prototypes. We will survey the most recent findings within this stream of research, and point out to current directions and challenges for the future.

Friday 10:20 Nettuno 4

LA6

Collective dynamics of motile cilia

Luigi Feriani, Maurizio Chioccioli, and Pietro Cicuta

Department of Physics, University of Cambridge, Cambridge, United Kingdom

Motile cilia are cell organelles able to exert a net force onto a liquid; they are highly conserved across eukaryotes, and enable a variety of functions from the motility of single cell organisms to flow that carries nutrients to our brains. A fascinating process takes place in mammalian airways: a carpet of motile cilia maintains the cell surface free of pathogens and particles by continuously refreshing and clearing a barrier of mucus. In order for this "muco-ciliary clearance" to be effective, cilia motion needs to be phase-locked across significant distances, in the form of a travelling wave, and it is not known how this is achieved. We image ex-vivo ciliated cell carpets, and extend on Differential Dynamic Microscopy creating a technique (multi-DDM) to quantify the spatial and temporal coherence in the cilia dynamics in a fully automated fashion. Employing multi-DDM on ciliated epithelia we show how the spatial coherence of the ciliary beat is affected by changes in the rheological properties of the mucus layer.

Friday 10:40 Nettuno 4

LA7

Non-linear rheology in a model biological tissueDaniel A. Matoz-Fernandez¹, Elisabeth Agoritsas², Jean-Louis Barrat³, Eric Bertin⁴, and Kirsten Martens⁴

¹*Division of Molecular Microbiology, University of Dundee, Dundee, United Kingdom;* ²*Laboratoire de Physique Théorique, École Normale Supérieure, Paris, France;* ³*Laboratoire Interdisciplinaire de Physique UMR 5588, University Grenoble Alpes, St Martin d'Heres, France;* ⁴*Laboratoire Interdisciplinaire de Physique UMR 5588, Centre National de la Recherche Scientifique, Saint Martin d'Hères, France*

Understanding the relation between the activity and mechanical properties of dense active matter is a topic of fundamental importance for many processes in nature. For instance, in a confluent biological tissue, mechanical signalling is known to play a key role in the collective dynamics of cells, being thus highly relevant to cancer growth or embryogenesis. One prominent way to probe the mechanical properties of such biological tissues is to study their response to externally applied forces. Using a particle-based model with pairwise soft interactions, featuring explicitly random apoptosis and environment-dependent division rates [1], we evidence a crossover from linear flow to a shear-thinning regime with an increasing shear rate. We rationalise this nonlinear rheology with a mean-field elasto-plastic scenario, inspired by the so-called Hébraud-Lequeux model [2], that accounts for the interplay of mechanical and active noise in local stresses [3]. These noises are, respectively, generated by the elastic response of the cell matrix to cell rearrangements and by the internal activity.

[1] Matoz-Fernandez, D. A. et al. (2017). *Soft matter*, 13(17), 3205-3212. [2] Agoritsas, E. & Martens, K. (2017). *Soft matter*, 13(26), 4653-4660. [3] Matoz-Fernandez, D. A. et al. (2017). *Physical review letters*, 118(15), 158105.

Friday 11:30 Nettuno 4

LA8

Rheology of pre-metastatic lung reveals stiffening after in vivo exposure to tumor-derived microparticlesTamar Barenholz-Cohen¹, Yulia Merkher¹, Dvir Shehter², Yuval Shaked², and Daphne Weihs¹

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The mechanics of the tumor microenvironment greatly affects the tumor growth rate, its invasive capacity, and the survival of tumor cells following treatment. Following chemotherapy, tumor cells respond by shedding increased numbers of tumor-derived microparticles (TMPs), i.e. 0.1-1µm extracellular vesicles. These TMPs have been shown to support tumor growth, for example by contributing to a rapid mobilization of bone marrow derived proangiogenic cells (BMDCs) towards the treated tumor site and likely also to potential metastatic sites. The BMDCs, with other local cells, are able to modify the microenvironment, making it more favorable to tumor cell seeding. However, the physical and mechanobiological changes in the pre-metastatic sites which support tumor cell seeding have not been evaluated. Here, we have evaluated the effects of TMPs shed from paclitaxel chemotherapy-treated breast cancer cells on their metastatic capacity towards the lungs and correlated with the lung rheology. We show that TMPs from invasive cells exposed to chemotherapy, increase the metastatic capacity of single cells making them more migratory and invasive. As a result, when such TMPs were injected into mice, the metastatic burden in the lungs increased, as compared to TMPs from control cells. To evaluate the rheology of the lung tissue in this context, mice injected with TMPs from control cells or cells exposed to paclitaxel, and the rheology of the entire lungs and lung slices was evaluated using a shear rheometer. We observe that the lungs are viscoelastic, with mucosal-like rheology. Further, using lung-slices we show sensitivity to local changes in the lung mechanics following *in vivo* treatments. Specifically, we show stiffening of the lung slices following exposure to TMPs and especially those treated by chemotherapy. These results further support the understanding how chemotherapy may induce a survival-driven response in tumors that may lead to tumor spreading.

Friday 11:50 Nettuno 4

LA9

Colloidal shuttles for programmable cargo delivery

Ahmet F. Demiroers

Materials, ETH Zurich, Zurich 8093, Switzerland

The active transport of cargo molecules within cells is essential for life. Developing synthetic strategies for cargo control in living or inanimate thermal systems could lead to powerful tools to manipulate chemical gradients at the microscale and thus drive processes out of equilibrium to realize work. Here we demonstrate a colloidal analog of the complex biological shuttles responsible for molecular trafficking in cells. Our colloidal shuttles consist of magneto-dielectric particles that are loaded with cargo particles or living cells through size-selective dielectrophoretic trapping using electrical fields. The loaded colloidal shuttle can be transported with magnetic field gradients before cargo is released at the target location by switching off the electrical field [1]. Such

spatiotemporal control over the distribution of chemically active cargo in a reversible fashion can be potentially exploited for fundamental biological research or for the development of novel technologies for advanced cell culturing, drug discovery and medical diagnosis.

[1] Demirörs, A. F. et al. (2017). Nature communications, 8(1), 1872.

Friday 12:10 Nettuno 4

LA10

Poised between order and disorder: stress and birefringence relaxation in sheared DNA solutions across the Isotropic-Nematic transition

Giuliano Zanchetta¹, Loredana Voelker-Pop², and Tommaso Bellini¹

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Hydrogels built from DNA are an attractive class of materials, with applications ranging from drug delivery to biosensing. Their structure and mechanical properties can be tuned by the design of physical crosslinks based on selective Watson-Crick base pairing [1]. Even simple systems of entangled DNA helices can display complex mechanical response, such as shear banding [2] and strain hardening [3]; however, in discussing such intriguing features, it is often disregarded that long DNA strands also undergo a transition to Nematic liquid crystalline phase at concentrations as low as few mg/ml [4]. We describe the behaviour of networks of DNA helices of thousands of base pairs. In a wide concentration range, the solutions are viscoelastic while also displaying a continuous transition from Isotropic to Nematic phase, without detectable phase separation. These solutions exhibit very weak equilibrium birefringence at rest, but strong transient birefringence when sheared. We measured the mechanical and optical response of sheared DNA networks to oscillatory and step deformations, across the transition region. To this aim, we combined rheology and real-space measurement of shear-induced alignment in a microscope shear cell, or through polarized reflection directly on the rheometer [5]. Both stress and birefringence relaxations are characterized by two time scales, a slow decay related to spontaneous disentanglement and a faster one, with different dependence on the applied strain for stress and birefringence. Such a behaviour is a consequence of the heterogeneity of the system: regions with higher local, Nematic order are more easily further aligned and fluidized than the isotropic, viscoelastic matrix in which they are embedded, resulting in a fast decay of birefringence already for linear deformations.

[1] Pan, W. et al. (2016). Soft matter, 12(25), 5537-5541. [2] Boukany, P. E. & Wang, S. Q. (2009). Soft Matter, 5(4), 780-789. [3] Orakdogan, N. et al. (2010). Macromolecules, 43(3), 1530-1538. [4] Merchant, K. & Rill, R. L. (1997). Biophysical journal, 73(6), 3154-3163. [5] Mykhaylyk, O. O. et al. (2016). Journal of Polymer Science Part B: Polymer Physics, 54(21), 2151-2170.

Friday 12:30 Nettuno 4

LA11

Polymer physics of chromosome 3D organisation

Mario Nicodemì

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I discuss the picture of chromosome spatial organization emerging from Hi-C or our recent GAM technology [1] in mouse and human cells and tissues. We mapped chromatin contacts, in particular, during neuronal differentiation [2]. We found that the genome is folded in a hierarchy of domains-within-domains. The higher-order organization extends across genomic scales and correlates with epigenomic features, highlighting a functional role of the spatial organization. Next, I discuss how architecture data and folding mechanisms can be understood by basic polymer physics (PRISMR) [3-5]. Using the EP4 locus as a model, I show that the effects of pathogenic mutations can be predicted. PRISMR accurately predicts the alterations of architecture and the rewiring of enhancer-promoter interactions, causing disease by gene misexpression. That opens the way to novel diagnostic methods.

[1] Beagrie, R. A. et al. (2017). Nature, 543(7646), 519. [2] Fraser, J. Et al. (2015). Molecular systems biology, 11(12), 852. [3] Chiariello, A. M. et al. (2016). Scientific reports, 6, 29775. [4] Barbieri, M. et al. (2017). Nature Structural and Molecular Biology, 24(6), 515. [5] Bianco, S. et al. (2017), submitted.

Symposium EM

Experimental Methods & Progress in Rheometry

Organizers: Christian Clasen, Salvatore Coppola and Qian Huang

Friday 10:00 Nettuno 5-6

EM1

Mono- and biconical geometries in rheometers: exact solution for the flow field and implications for the design of measuring systems

Philipp W. Bohr and Heiko Stettin

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Literature on rheometry [1, 2] so far only grants formulae for the torque in Cone-Plate geometry in approximation for small gap angles, which lead to a shear rate distribution that shows no polar variation. Hence, the torque measured does not depend on the gap angle, and neither do the strain or stress conversion factors. Our calculations show that the Navier-Stokes equation for rheometric flows with conical boundary conditions are analytically solvable and lead to a closed-form expression for the velocity, the shear rate and the torque exerted on the confining interfaces. These findings are used to derive correction factors that become of particular importance in geometries with steeply-inclined cones. We furthermore exploit the formalism for the engineering of a new set of measuring systems that we name "Cone-Pan" where a cone rotates over a conical cavity. Results from experiments as a proof of concept of this geometry will be provided with our work.

[1] Macosko, C. W. (1994). *Rheology: Principles, Measurements and Applications*, Wiley-VCH, New York. [2] Powell R. L. (1998). *Rheological Measurement*, Chapman & Hall, London.

Friday 10:20 Nettuno 5-6

EM2

Structural rheology at multiple time and length scales

Eric Stellamanns¹, Fabian Westermeier, Stephan Schulze, Daniel Weschke, Eiryn Müller, and Michael Sprung
Photon Science, German Electron Synchrotron, Hamburg, Hamburg 20255, Germany

Structural rheology happens over multiple time and length scales, hence understanding the rheological properties of complex fluids under shear needs observation of all relevant scales simultaneously. By combination of optical and x-ray scattering techniques with a stress and temperature controlled rheometer, we are able to provide insight into the complex structure of flow from the nano- to the mesoscale. Based on an inverted Haake MARS II rheometer, we developed a specialized set of rheo sensors that are transparent for both, high and low energy electromagnetic radiation together with a high temperature probe environment and solvent trap that allows for the x-ray beam to pass through and provides apertures for the x-ray detector together with a high resolution microscope. With this toolbox, it is now possible to examine shear and temperature induced mechanical changes in a material and directly correlate them to structural changes: 1) on the molecular scale by wide angle x-ray scattering, 2) on the nano scale by small angle scattering and 3) on the mesoscale by polarisation microscopy and wide field observation. In this way, a wide range of materials can be examined, from water based biological systems or colloidal suspensions making use of the solvent trap, to highly temperature sensitive liquid crystals or high performance polymers that melt at 300°C and above. Given the high brilliance and flux of the PETRA III synchrotron in addition to reduced background scattering by the sensors and a fast 2D detector, we achieved a temporal resolution up to 1 kHz for time resolved x-ray scattering. In combination with the high coherent fraction of the beam it is not only possible to conduct time resolved SAXS and WAXS but also to conduct x-ray photon correlation spectroscopy experiments (XPCS) and quantify both, the structure and the dynamics of colloidal suspension under shear and after cessation of shear.

Friday 10:40 Nettuno 5-6

EM3

Rheo-NMR, a combination of nuclear magnetic resonance (NMR) and rheometry to provide complementary information on the rheological properties of matter

Dieter Gross¹, Timothy Brox², Thomas Oerther¹, and Petrik Galvosas²

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Rheo-NMR utilises nuclear magnetic resonance (NMR) techniques to investigate the molecular dynamics and the local mechanical response of materials under shear [1]. By combining NMR spectroscopy with rheometry methods, Rheo-NMR can be used to probe the molecular origins of the macroscopic bulk rheological response or to study non-homogeneous deformations spatially resolved. In recent years, Rheo-NMR techniques have been expanded by the development of new hardware [2]. These improvements have seen the introduction of oscillatory shear for Rheo-NMR which was recently used to study multilamellar vesicle formation of a non-ionic surfactant system [3]. Additionally, instruments which incorporate torque sensing elements enable for rheological flow curves to be acquired simultaneously with the NMR data acquisition [4, 5]. This allowed to demonstrate that the onset of shear-banding may vary depending on the geometric parameters of the shear device used [5]. In this contribution the technical components of the Rheo-NMR hardware are explained as well as introducing NMR experiments commonly used with to study materials under shear. To demonstrate the principles of Rheo-NMR, examples are given using sodium lauryl ether sulfate (SLES). These examples include spatially resolved velocity maps across the gap of a concentric cylinder shear geometry as a function of applied strain rates to visualise the local shear rate distribution and the change from Newtonian to shear thinning behaviour. Additionally, deuterium spectra show the dependency of molecule alignment at different shear rates and at different temperatures.

[1] Callaghan, P.T. (1999). *Reports on Progress in Physics*, 62(4), 599. [2] Brox, T. & Galvosas, P. (2016). *New Zealand Patents* 629361 & 629586. [3] Kuczera, S. et al., in preparation. [4] Grabowski, D. A. & Schmidt, C. (1994). *Macromolecules*, 27(9), 2632-2634. [5] Brox, T. I. et al. (2016). *Journal of Rheology*, 60(5), 973-982.

Friday 11:30 Nettuno 5-6

EM4

Experimental investigation of the flow dynamics and rheology of complex fluids in pipe flow by hybrid multi-scale velocimetry

Sanna Haavisto¹, Juha Salmela¹, Markku Kataja², and Antti I. Koponen³

¹*Spinnova Ltd, Jyväskylä, Finland;* ²*University of Jyväskylä, Department of Physics, Jyväskylä, Finland;* ³*VTT - Technical Research Centre of Finland, Jyväskylä, Finland*

A hybrid multi-scale velocimetry method utilizing Doppler Optical Coherence Tomography (DOCT) in combination with Ultrasound Velocity Profiling (UVP) is used to investigate pipe flow of softwood fiber suspension, and a microfibrillated cellulose suspension. The measurement setup enables not only the analysis of the rheological (bulk) behavior of a studied fluid but gives simultaneously information on their wall layer dynamics, both of which are needed for analyzing and solving practical fluid flow related problems. Novel results on rheological and boundary layer flow properties of the working fluids are reported and the potential of the hybrid measurement setup is demonstrated.

Friday 11:50 Nettuno 5-6

EM5

Data driven calibration of in line viscosity sensorsAlessandra Taris¹, Roberto Mei¹, Massimiliano Grosso¹, Stefania Tronci¹, Francesc Corominas², and Paul Van Neer³¹*Dipartimento di Ingegneria Meccanica, Chimica e dei Materiali, Università degli Studi di Cagliari, Cagliari, Italy;*²*Procter & Gamble Eurocor N.V., Strombeek-Bever, Belgium;* ³*TNO Science and Industry, Rotterdam, The Netherlands*

In-line sensors for the inference of the viscosity might be a powerful tool for the monitoring of quality, where the use of traditional offline rotational viscosity meters is not feasible. Recently, ultrasound based sensors were proposed to perform rapid evaluation of the viscosity of flowing materials, such as e.g. the viscosity-shear rate curve [1]. Although preliminary results obtained with these techniques seem to be promising, consolidated protocols are not definitely available in the marketing yet. In this contribution, we propose a data driven approach, where outputs provided by a new sensor developed by TNO are compared with offline measurements. Measurements were carried out at pilot plant scale. The production of liquid composition is mimicked in presence of flow feed variations of the compounds. Notice that the composition revealed a non-Newtonian behavior strongly depending on the compound concentrations [2]. Black box data driven models were implemented to correlate the sensor data with the viscosity measurements carried out offline with a TA-2000 strain controlled viscosity meter. The models show a good performance in predicting the viscosity values at different shear rates and it reveals as a valuable alternative to first principle calibration of the sensor. In addition, the results may give useful insights on the physics underlying the process. This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 636942.

[1] Meacci, V. et al. (2016). IEEE Sensors Applications Symposium, 1-6. [2] Corominas, F. et al. (2013). Patent US 2013/0225468 A1.

Friday 12:10 Nettuno 5-6

EM6

Measuring the adhesion limit of cells with a narrow-gap rotational rheometerHaider Dakhil¹, Hung Do¹, Holger Hübner², and Andreas Wierschem¹¹*Lehrstuhl für Strömungsmechanik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen 91058, Germany;*²*Lehrstuhl für Bioverfahrenstechnik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen 91052, Germany*

The adhesion of cells to a substrate is crucial for implants and biofilms. As a test case, we study the adhesion limit of 3T6 Swiss mouse fibroblasts with a modified narrow-gap rotational rheometer in the parallel-disk configuration [1-3]. Reducing the uncertainty in gap width to about 1 μm allows studying the cells at narrow gaps, which on the other hand enables studying the adhesion limit of the cells in low-viscous media. The cells were fixed to the lower glass plate with fibronectin close to the rim of the gap between the disks. The critical shear stress was determined as the one at which half of the cells detach from the substrate. The critical shear stress depends on the fibronectin concentration and cell adhesion time. We show that the setup may also be used for cells grown in place.

[1] Dakhil, H. & Wierschem, A. (2014). Applied Rheology, 24(6), 63795-63801. [2] Dakhil, H. et al. (2016). Rheologica Acta, 55(7), 527-536. [3] Dakhil, H. et al. Bioprocess and biosystems engineering, accepted.

Friday 12:30 Nettuno 5-6

EM7

Computing the linear viscoelastic properties of soft gels using an Optimally Windowed Chirp protocolMehdi Bouzid¹, Bavand Keshavarz², Michela Geri², Thibaut Divoux³, Emanuela Del Gado⁴, and Gareth H. McKinley²¹*University of Paris Sud, Paris, France;* ²*Mechanical Engineering, MIT, Cambridge, MA 02139, United States;* ³*Civil & Environmental Engineering MIT, CNRS, Cambridge, MA 02139, United States;* ⁴*Physics, Georgetown University, Washington, DC 20057, United States*

We show that the recently developed Optimally Windowed Chirp (OWCh) technique allows for an efficient computation of the linear rheological response in numerical simulations of soft attractive gels. Accurate and fast computations of the viscoelastic spectrum of such gels are challenging because of the wide range of frequencies and the typically low signal-to-noise ratio of the rheological response. We use damped molecular dynamic simulations of a model three-dimensional particulate gel, specifically designed to investigate soft gels at low volume fraction through the use of interparticle interactions that are attractive and anisotropic. The numerical simulations are combined with the novel test protocol (OWCh) in which a continuous exponentially varying frequency sweep windowed by a tapered cosine function is applied and the mechanical response of the gel is analyzed in the Fourier domain. In addition to demonstrating that OWCh leads to an accurate computation of the full frequency spectrum at a rate that is significantly faster than with the traditional discrete frequency sweeps, we make use of this computational efficiency to help rationalize the viscoelastic response of the microscopic model in terms of a mesoscopic constitutive model. We show that the gel response is well described by a simple mechanical model corresponding to a fractional Kelvin-Voigt model with a single Scott-Blair (or springpot) element and a spring in parallel. Varying the viscous damping and the particle mass chosen in the simulations over a wide range of values, we demonstrate the existence of a single master curve for the frequency dependence of the viscoelastic response of the gels that is fully predicted by the constitutive model. Hence our results provide a first quantitative link between the microstructural model and the fractional Kelvin-Voigt mechanical model, opening the path to novel multiscale insight into rheological data for such complex materials.

Friday Afternoon

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Friday 14:20 Sirene

CS42

Computer simulations of packed soft colloids

Tom Ridley¹, Oliver G. Harlen¹, Daniel J. Read¹, and Johan Mattsson²

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'Soft' colloids are typically micron or sub-micron scale structured objects such as polymer microgels, which consist of chemically cross-linked polymer networks that are compressible and deformable. Experiments suggest that at packing ratios where the structural dynamics of hard colloids are arrested, a soft colloid system may still be able to undergo cage-breaking due to particle deformation. However, the link between the detailed elastic properties of soft colloids and the resulting dynamics are not presently well understood. Soft packed colloids show rich and complex rheological and flow behaviour and it is important to derive the links between the single particle elastic properties and the resulting suspension's behaviour. In this paper we will present the results of numerical simulations of packed viscoelastic particles to explore the dynamics of soft colloids, including behaviour under thermal motion alone and in shear flow across a range of uncompressed volume fractions, and compare with previous work on hard and soft colloids. Our simulations utilise a recently developed computational algorithm, Fluctuating Finite Element Analysis, for simulating viscoelastic objects undergoing thermal excitation. While colloidal systems characterised by hard or radially symmetric soft potentials have been much studied, this approach captures the detailed shape deformations of the colloidal particles and ensures that the structure of the objects as well as the effect of anisotropic deformation are taken into account. We present results showing the effects of varying the viscoelastic properties of the colloidal particles and we find evidence of cage-breaking events continuing to take place even where the effective volume fraction exceeds the volume fraction at which hard colloids become arrested.

Friday 14:40 Sirene

CS43

Gelation as condensation frustrated by hydrodynamics and mechanical isostaticity

Hideyo Tsurusawa¹, Mathieu Leocmach², John Russo³, and Hajime Tanaka¹

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Colloidal gels have unique mechanical and transport properties that stem from their bicontinuous nature, in which a colloidal network is intertwined with a viscous solvent, and have found numerous applications in foods, cosmetics, construction materials, and for medical applications, such as cartilage replacements. So far, our understanding of the process of colloidal gelation is limited to long-time dynamical effects, where gelation is viewed as a phase separation process interrupted by the glass transition. However, this picture neglects the influence of mechanical factors emerging from the presence of both the incompressibility of the solvent and the elasticity of network. With confocal microscopy experiments, here we successfully follow the entire process of gelation with a single-particle resolution, yielding time-resolved measures of internal stress and visco-elasticity from the very beginning of the aggregation process. First, we demonstrate that the presence of a liquid component constrains the initial stage of phase separation, enhancing the formation of a percolated network. Then we show that this network is not mechanically stable and undergoes rearrangements driven by self-generated internal stress. Finally, we show that mechanical metastability is reached only after percolation of locally isostatic environments, proving isostaticity a necessary condition for the load bearing ability of gels rather than the glass transition.

Friday 15:00 Sirene

CS44

Wall slip under unconfined conditions

Xiao Zhang¹, Élise Lorenceau², and Philippe Coussot¹

¹*Université Paris-Est, Champs-sur-Marne 77420, France;* ²*Université Grenoble Alpes, Grenoble, France*

Concentrated suspensions which are yield stress fluids, flow only when submitted to a stress greater than a critical stress. However, on smooth surfaces, they can move under smaller stresses. This phenomenon, called wall-slip, has been studied in rheometrical conditions for which the sample is confined between two solid surfaces. We recently showed [1] that the residual slip yield stress is due to an edge effect, and that the stress purely associated with the wall slip corresponds to a simple shear of an apparent Newtonian layer of thickness in a narrow range for many materials of various micro-structures, concentrations and physio-chemical interactions. Here we present new experimental data with model systems (simple emulsions) providing a further insight in the mechanism of wall slip.

First we confirm the edge effects by tests at different times of rest. Then we show that the wall slip law is independent of the normal stress (up to the yielding value) applied to the system, which means that wall slip is not the result of some equilibrium between internal forces and liquid flow along the interface. We also show that more generally the wall slip is independent of the flow history and boundary conditions, through experiments in steady or transient conditions, confined or free surface conditions. These also

proved that the wall slip layer is continuously refilled by the interstitial liquid. Finally we show that the wall slip law is independent of the element size, which means that the liquid flow in the slip layer is independent of any flow through the porosity (or roughness) of the jammed system along the wall. From these elements we sketch a model of wall slip process based on a jammed structure in contact with the wall via a limited number of very close approach of the elements still lubricated by a nanometric layer. This model seems to be supported by further experiments with model rough surfaces.

[1] Zhang, X. et al. (2017). Physical review letters, 119(20), 208004.

Friday 15:20 Sirene

CS45

The glass transition of soft colloids

Adrian-Marie Philippe¹, Domenico Truzzolillo¹, Julian Galvan-Miyoshi², Philippe Dieudonné-George¹, Véronique Trappe², Ludovic Berthier¹, and Luca Cipelletti¹

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By combining rheology, light scattering, small angle X-ray scattering and simulations we explore the glassy dynamics of soft colloids using microgels and charged particles interacting by steric and screened Coulomb interactions, respectively. In the supercooled regime, the structural relaxation time (SRT) of both systems grows steeply with volume fraction, reminiscent of the behavior of colloidal hard sphere systems [1]. This suggests that softness has no impact on the growth of the SRT on approaching the glass transition, as confirmed by computer simulations. We show that the onset of a finite yield-stress, occurring within the supercooled regime, systematically corresponds to a minimum of the stretching exponent characterizing the decay of the two-time intensity autocorrelation function. Softness becomes relevant only at very large packing fractions, when the system falls out of equilibrium. In this non-equilibrium regime, the SRT depends surprisingly weakly on packing fraction and time correlation functions exhibit compressed exponential decays consistent with internal stress-driven relaxation. The transition to this novel regime coincides with the onset of an anomalous decrease of local order with increasing density, reminiscent of the reentrant glass transition predicted theoretically in ultrasoft systems [2,3], and corresponds to a weakening of the volume fraction dependence of the plateau modulus of the suspensions. We propose that these peculiar dynamics result from a competition between the non-equilibrium aging dynamics of the glassy state and the tendency of soft systems to refluidize at high packing fractions.

[1] Brambilla, G. et al. (2009). Physical review letters, 102(8), 085703. [2] Zhang, Z. et al. (2009). Nature, 459(7244), 230. [3] Graves, S. et al. (2005). The Journal of Chemical Physics, 122(13), 134703.

Friday 15:40 Sirene

CS46

Rheology of non-spherical granular suspensions

Vinay V. Mahajan, Junaid Mehmood, Fitzgerald Barry, and Johan T. Padding
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While colloidal suspensions of nonspherical particles have been studied relatively extensively, granular suspensions of nonspherical particles are rarely studied. The rheological behaviour of elongated granular particles is therefore not well known. In this work, we study suspensions of rod-like particles of aspect ratio 4 subjected to shear flow in a low-density Newtonian fluid. We perform CFD-DEM simulations for a periodic shear box while controlling the suspension properties. We discuss the dependence of stress, pressure, and relative viscosity on volume fraction, shear rate, granular temperature and the particle orientation. Perhaps surprisingly, the granular rods show shear thickening behaviour. These results provide insights into the macroscopic rheology of suspensions of randomly oriented and oriented granular rods.

Friday 16:30 Sirene

CS47

Can soft colloids jam? A comparison between polyelectrolyte microgels and star polymers

Leo Gury¹, Dimitris Vlassopoulos¹, Michel Cloitre², and M. Gauthier³

¹Department of Materials Science and Technology, FORTH, University of Crete, Crete, Greece; ²Laboratoire Matière Molle et Chimie, ESPCI ParisTech, Paris 75005, France; ³Department of Chemistry, University of Waterloo, Waterloo, Canada

Recently, dense microgel suspensions were shown to exhibit a thermal glass-to-jammed glass transition, characterized by larger yield stress and strain and linear dependence of plateau modulus on concentration in the jammed state, as well as other subtle differences in flow curves [1, 2]. There appears a consensus calling for shape adjustment in the highly concentrated regime as the origin of jamming [3]. On the other hand, it is well-known that linear polymer coils do not show comparable features, instead they exhibit a smooth evolution of their rheological properties from semi-dilute to entangled to melt regimes [4]. Given that hairy particles represent a distinct class of soft colloids, being essentially the counterpart of microgels [5], a natural question is whether they experience such jamming transition at high concentrations and which are its possible signatures. Here we address this question and report our findings on highly concentrated suspensions of an 800-arm star polymer that encompasses properties of both colloids and polymers, and compare our results to moderately crosslinked polyelectrolyte microgel suspensions. Whereas both types of particles are supposedly able to shrink and deform under the action of internal osmotic pressure, star polymers are additionally prone to interpenetration while our microgels do not possess significant dangling chains. This difference in particle architecture may well explain both the common features and the differences in the rheological behavior of these soft colloids. We focus on linear and nonlinear rheological measurements and analysis encompassing polymeric and colloidal features, based on which we conclude that jamming of long hairy particles is a subtle issue.

[1] Pellet, C. & Cloitre, M. (2016). Soft Matter, 12(16), 3710-3720. [2] Yodh, A. G. et al. (2010). Physical review letters. [3] Conley, G. M. et al. (2017). Science advances, 3(10), e1700969. [4] Rubinstein, M. & Colby, R. H. (2003). Polymer physics, New York, Oxford university press. [5] Vlassopoulos, D. & Cloitre, M. (2014). Current opinion in colloid & interface science, 19(6), 561-574.

Friday 16:50 Sirene

CS48

Hallmarks of local intermittent relaxation events in the creep behavior of a colloidal gelVéronique Trappe¹, Davide C. Calzolari¹, Irmgard Bischofberger², and Francesco Nazzari¹¹*Department of Physics, University of Fribourg, Fribourg, Switzerland;* ²*Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, United States*

We explore the dynamical and mechanical characteristics of an evolving gel, aiming in particular to assess how the gel evolution impacts the creep response of the system. We find that the creep behavior of the gel is determined by three distinct contributions: an instantaneous elastic, a delayed elastic and a loss contribution. The systematic investigation of these contributions in recovery experiments provides evidence that delayed elastic and loss contributions relate to the same process, namely local intermittent relaxation events that also govern the structural relaxation of the gel at quiescent conditions. Upon increasing the stress towards the yield stress our experimental findings suggest that the size of the restructured zones per event increases, while the rate of intermittent relaxation events remains essentially unchanged.

Friday 17:10 Sirene

CS49

High speed confocal microscopy of sheared colloidal gels

Gabriele Colombo and Jan Vermant

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Colloidal gels represent an interesting family of soft materials. Despite the wide range of possible technological applications, the microstructural details underlying their typical solid-to-liquid transitions upon shear remain poorly understood, therefore posing challenges for industrial formulations. This stems from their hierarchical, strongly heterogeneous structure, lying at the roots of their bulk mechanical properties. The rheology of colloidal gels is very sensitive to the applied flow history and typically shows a complex behavior including a yield stress and thixotropy. Dramatic changes in mechanical properties may well result from subtle, highly localized microstructural changes, which are difficult to resolve using scattering experiments. In this work, we intend to evaluate the microstructural basis of thixotropy, varying the packing behavior in model colloidal gels by changing the particle aspect ratio slightly. The experimental approach relies on the quantitative study of the gel microstructure using high-speed confocal microscopy. Microscopic studies under flow are performed using a stress controlled rheometer with a home-made shear cell for counter-rotation of the lower plate, allowing single particles to be located and tracked for long times at the stagnation plane. The stress is directly measured, so that the link between microscopic observations and nonlinear rheology can be established. We also intend to clarify the role of microstructural anisotropy under flow, resulting in the butterfly scattering patterns observed for colloidal gels. Recent simulation approaches also show the emergence of large structural elements in the vorticity direction of flow, whose relevance for the rheological properties of gels was recently shown by two-dimensional oscillatory measurements on a model thixotropic gel. Such anisotropic structural features are observed here in sheared model, depletion colloidal gels, as evidenced by the Fourier transform power spectra and by real space analysis.

Friday 17:30 Sirene

CS50

Yielding mechanisms and internal relaxations in sheared attractive glasses

George Petekidis and Esmaeel Moghimi

Institute of Electronic Structure & Laser, IESL, Foundation for Research & Technology-Hellas, FORTH, Heraklion, Crete, Greece

We investigate the microscopic dynamics and structural effects induced by shear in concentrated suspensions of colloids with attractive interactions. Moreover we probe the effect of attractions in the rheological response of colloidal glasses during yielding using a combination of experiments and computer simulation. We mainly focus on the way such systems yield under the application of steady or oscillatory shear via start-up shear tests and large amplitude oscillatory shear, as well as on the mechanisms of structural reformation and related stress relaxation after shear cessation. We discuss the phenomenology of two-step yielding, widely observed experimentally, its relation with quiescent microscopic dynamics and the underlying mechanisms affecting the relevant length- and time-scales during shear. Both experiments and Brownian Dynamics (BD) simulations show two peaks in stress versus strain during start-up shear tests with good qualitative agreement suggesting that Hydrodynamic Interactions are not crucially important at such highly concentrated systems. Structural analysis at single particle level obtained from BD simulations confirms that the first yield point is related with structural changes at length-scales of the order of the bond range while the second yield is a consequence of larger length-scale rearrangements linked with cage deformation and breaking. In relation with the above we also probe shear induced internal relaxations and linear viscoelastic properties by Orthogonal Superposition Rheometry, where a small amplitude oscillation probes the sheared systems in the orthogonal direction. The results from attractive glasses are contrasted with similar experiments in hard sphere glasses in order to unravel the effect of interparticle attractions at different shear rates and attraction characteristics (range and strength).

Friday 17:50 Sirene

CS51

Dense vesicle suspensions: relaxation processes and dynamic heterogeneitiesRaffaele Pastore¹, Marco Caggioni², Francesco Greco¹, Vincenzo Guida³, Stefano Guido¹, and Guido Raos⁴¹*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy;* ²*Procter & Gamble, Cincinnati, OH, United States;* ³*Procter & Gamble, Bruxelles, via Newton, Belgium;* ⁴*Cmic, Politecnico di Milano, Milano, Milano 20131, Italy*

Concentrated suspensions of charged vesicles are widespread in consumer products, including fabric enhancers made up of cationic quaternary ammonium surfactants in salty water. Rheology and appearance of such suspensions are known to be dramatically sensitive to aging, minor changes in the preparation protocol and other small perturbations, but the underlying physical mechanisms are still not clear. In order to elucidate these issues, we are currently performing a combined numerical and experimental study. On

the numerical side, we define a model that grasps the key features of charged vesicle suspensions, consisting of polydisperse particles interacting via a DLVO-like potential, and perform Molecular Dynamics simulations for a range of different system control parameters, such as particle volume fraction and interaction strength. On the experimental side, we exploit our Differential Variance Analysis [2] to monitor the structural relaxation from digital video microscopy. In this talk, we will show that the high susceptibility of dense vesicle suspensions arises from the proximity to a liquid-glass transition. Indeed, we recover the distinctive dynamic signatures characterizing molecular and colloidal glass formers both on the microscopic and the macroscopic scale. These include cage-jump motion at the single particle level [3], dynamic heterogeneities and sluggish relaxation. Finally, we will discuss how these dynamic features affect the rheology.

[1] Seth, M. et al. (2014). *Langmuir*, 30(34), 10176-10187. [2] Pastore, R. et al. (2017). *Scientific Reports*, 7, 43496. [3] Pastore, R. et al. (2017). *The Journal of Physical Chemistry Letters*, 8(7), 1562-1568.

Symposium NF

Non Newtonian Fluid Mechanics & Flow Instabilities

Organizers: Patrick Anderson, Peter Olmsted and Fernando Tavares de Pinho

Friday 14:20 Ulisse

NF42

Delay of symmetry-breaking instability in cross-slot geometries using a passive flow- control mechanism

Mahdi Davoodi, Allysson Domingues, David j. Dennis, and Robert J. Poole

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Delay of symmetry-breaking instability in cross-slot geometries using a passive flow- control mechanism M Davoodi, A Domingues, D J C Dennis, R J Poole School of Engineering, University of Liverpool, Liverpool, L69 3GH, UK. The cross-slot stagnation point flow is one of the benchmark problems in fluid mechanics as it allows large strains to develop and can therefore be used for extensional rheometry. In such a flow, beyond a critical value in which the ratio of inertia force to viscous force is high enough, inertia can break symmetry. Another form of symmetry-breaking has also been observed for purely-elastic cases in creeping flow regimes, which is perhaps an unwanted phenomenon if used as a rheometer. In this work, a passive control mechanism is introduced by adding a cylinder at the geometric centre of the cross-slot geometry to replace the free stagnation point with "pinned" stagnation points at the surface of the cylinder. In the current modified geometry, effects of the blockage ratio (the ratio of diameter of the cylinder to the width of the channel), the Weissenberg number (the ratio of the elastic forces to viscous forces) and extensibility parameter (ϵ) are investigated in 2D numerical simulations using a simplified Phan-Thien and Tanner model. It is shown that the blockage ratio for fixed solvent-to-total viscosity ratio has a stabilizing effect on the associated symmetry-breaking instability. Further results show that the Weissenberg number and ϵ parameter have a destabilizing and stabilizing effect, respectively. Numerical simulations supported by experimental results show that the suggested modifications, replacing the free stagnation point with pinned stagnation points, can change the super critical nature of the instability in the cross-slot geometry. The investigation also suggest that the proposed geometry modification can be an effective approach to reach a higher flow rate whilst retaining steady symmetric flow in a cross-slot.

Friday 14:40 Ulisse

NF43

Instability of pressure driven channel flows of shear-thinning viscoelastic fluids

Hugh J. Barlow¹, Ewan J. Hemingway¹, Andrew Clarke², and Suzanne M. Fielding¹

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We examine the instability of shear-thinning pressure-driven channel flow to undulations with wavevector in the flow direction. By means of linear stability analysis and full nonlinear simulations across a suite of commonly used constitutive models, including the microscopically motivated Rolie-Poly model of linear entangled polymers and the phenomenological Johnson-Segalman, Giesekus and FENE-P models, we demonstrate the instability to be rather generic across shear thinning fluids. This finding is consistent with the original predictions of [1] in the context of the White-Metzner model, and with recent experiments [2-4]. We consider the way in which the onset of the instability depends on the variation in the flow properties across the channel. These result from the stress gradient that is inherent to channel flows, combined with the shear thinning properties of the fluid and the dependence of the first normal stress on strain rate. We study these factors by comprehensively varying across simulation runs the values of the model parameters and imposed pressure drop.

[1] Wilson, H. J. & Rallison, J. M. (1999). *Journal of non-newtonian fluid mechanics*, 87(1), 75-96. [2] Bodiguel, H. et al. (2015). *Physical review letters*, 114(2), 028302. [3] Poole, R. J. (2016). *Physical Review Fluids*, 1(4), 041301. [4] Picaut, L. et al. (2017). *Physical Review Fluids*, 2(8), 083303.

Friday 15:00 Ulisse

NF44

A combined experimental and theoretical study on draw resonance in polymer melt spinning

Mathias Bechert

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In polymer melt fiber spinning, the molten material is extruded through a circular die and taken-up by a spinning wheel. The ratio of take-up to extrusion velocity, the so-called draw ratio, constitutes the primary control parameter. If it exceeds a critical value, the draw resonance mechanism leads to unstable flow behavior. In this talk, we analyze experimentally the draw resonance effect for two polypropylenes. The fiber diameter is filmed with a camera and the averaged fluctuations are evaluated at several positions in

height. The critical conditions can then be determined by employing the stationary Landau-Ginzburg equation. Moreover, a Fourier analysis makes an evaluation of the oscillation frequency at criticality possible. The experimental findings are then compared to theoretical predictions obtained by a linear stability analysis of an averaged one-dimensional, single mode PTT model. Even though the materials exhibit a rather broad distribution of the molecular mass, it is possible to determine an effective relaxation time, which enables a satisfying description of the measured critical draw ratio.

Friday 15:20 Ulisse

NF45

Flow characteristics of visco-elastic fluids injected from a nozzle

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Flow characteristics of visco-elastic fluids injected from a nozzle into air have been investigated. As viscoelastic fluids, the dilute solutions of polyethylene oxide as flexible polymer, of hydroxypropylcellulose as rigid polymer and of polyacrylic acid as shrinkable polymer were used. The injection filaments, the droplets and the satellites of fluids from a nozzle with the diameter of 0.5 mm injected by a piezoelectric element were observed by a high-speed video camera. Injection velocity was changed from 2.04 to 4.76 m/s, which apparent extensional rate ranged from 2,270 to 5,270. From the results, it was found that each filament length of each fluid increases monotonically with Weissenberg number and all data can be plotted in one curve independently of materials, while the tendency does not depend on the inverse number of Ohnesorge number which is frequently used for Newtonian fluids. Each droplet size was also found to increase with the Weissenberg number and to be plotted on one curve. Thus, the filament length and the droplet diameter were concluded to depend on Weissenberg number, respectively. In the presentation, flow fluctuation characteristics will be also discussed.

Friday 15:40 Ulisse

NF46

Instability of non-Newtonian extensional flows

Roiy Savag¹ and Grae M. Worster²

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The interface of a fluid that displaces another fluid in a quasi-two dimensional geometry can develop fingering patterns. This includes for example flows in porous media and flows of gastric acids in the stomach. It is believed that the interface remains stable, having a planar or circular shape, when the displacing fluid is more viscous. However, some systems, such as ice sheets propagating into the ocean or squeezed pastes demonstrate fingering patterns in spite of having a more viscous displacing fluid. Here we show that fingering patterns emerge when circular interfaces of strain-rate-softening fluids displace less viscous fluids along slippery boundaries. The width of the fingers grows through the merging of adjacent fingers at times that we are able to predict. Such patterns do not occur when the displacing fluid is Newtonian. Our findings suggest that such instability could arise in any strain-rate-softening material under circular extension, and imply new strategies to inhibit or trigger fingering.

Friday 16:30 Ulisse

NF47

Effect of die exit stress state, Deborah number, uniaxial and planar extensional rheology on the neck-in phenomenon in polymeric flat film production

Martin Zatloukal and Tomáš Barborík

Polymer Centre, Tomas Bata University in Zlin, Faculty of Technology, Zlin, Czech Republic

In this work, effect of the second to first normal stress difference ratio at the die exit, $-N_2/N_1$, uniaxial extensional strain hardening, $\eta_{E,U,max}/(3 \times \eta_0)$, planar-to-uniaxial extensional viscosity ratio, $\eta_{E,p}/\eta_{E,U}$, and Deborah number, De , has been investigated via viscoelastic isothermal modeling utilizing 1D membrane model and a single-mode modified Leonov model as the constitutive equation. Based on the performed parametric study, it was found that there exists a threshold value for De and $\eta_{E,U,max}/(3 \times \eta_0)$, above which, the neck-in starts to be strongly dependent on $-N_2/N_1$. It was found that such critical De decreases if $-N_2/N_1$, $\eta_{E,U,max}/(3 \times \eta_0)$ increases and/or $\eta_{E,p}/\eta_{E,U}$ decreases. Numerical solutions of the utilized model were successfully approximated by a dimensionless analytical equation relating the normalized maximum attainable neck-in with $\eta_{E,U,max}/(3 \times \eta_0)$, $\eta_{E,p}/\eta_{E,U}$, $-N_2/N_1$ and De . Suggested equation was tested by using literature experimental data. It was found that approximate model predictions are in a very good agreement with the corresponding experimental data for low as well as very high Deborah numbers, at which neck-in strongly depends on $-N_2/N_1$. It is believed that the obtained knowledge together with the suggested simple model can be used for optimization of the extrusion die design (influencing flow history and thus die exit stress state), molecular architecture of polymer melts and processing conditions to suppress neck-in phenomenon in production of very thin polymeric flat films.

The authors wish to acknowledge Grant Agency of the Czech Republic (Grant registration No. 16-05886S) for the financial support.

Friday 16:50 Ulisse

NF48

Physical stability of structured fluids containing air bubbles

Shadi Mirzaagha¹, Rossana Pasquino¹, Nino Grizzuti¹, Vincenzo Guida², and Fabio Zonfrilli²

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Home-care products are detergent systems that differ for applications, formulation and structure. From a physical point of view, detergents are usually suspensions where a surfactant-based, worm-like micellar solution represents the continuous phase and colloidal fibers are added in order to provide the matrices of specific properties, e.g. the ability to suspend pigments, oil droplets, perfumes. In spite of the many advantages assured by the presence of the fibers in terms of shelf life, the resulting system can be mechanically unstable. The main responsible for this instability is the load applied by air bubbles, which are found into the final product, due to the process itself. Academic and product-oriented researchers are interested in understanding the failure dynamics

and, ultimately, in obtaining predictions on the physical stability of structured fluids over ageing. Hence, the aim of this work is to analyze the physical stability of a structured detergent in presence of air bubbles. We studied various samples, which differ from each other for aeration level and fiber concentration. The rheological behavior and the microstructure of these fluids has been characterized. In parallel, a time lapse photography technique has been used to monitor the time evolution of the air bubbles trapped in the fluids. The motion of single bubbles as well as the cooperative motion of bubble ensembles have been analyzed to verify the possibility of microstructure collapse. We found that fiber concentration, which dictates the yield stress of the fluid, aeration level and temperature can influence the stability of the final product. In particular, under given conditions, bubbles can apply a remarkable load on the fiber network during their buoyancy-driven rise, thus inducing the collapse of the structure. Data have been critically analyzed and compared with theoretical predictions and simulation model made by Comsol Multiphysics software.

Friday 17:10 Ulisse

NF49

Inertioelastic flow instability at a stagnation point

Noa Burshtein¹, Konstantinos Zografos², Amy Q. Shen¹, Robert Poole², and Simon J. Haward¹¹Okinawa Institute of Science and Technology, Onna, Okinawa 904-0495, Japan; ²University of Liverpool, Liverpool, Liverpool L69 7ZX, United Kingdom

A number of important industrial applications exploit the ability of small quantities of high molecular weight polymer to suppress instabilities that arise in the equivalent flow of Newtonian fluids, a particular example being turbulent drag reduction. However, it can be extremely difficult to probe exactly how the polymer acts to, e.g. modify the streamwise near-wall eddies in a fully turbulent flow. Using a novel cross-slot flow configuration, we exploit a flow instability in order to create and study a single steady-state streamwise vortex. By quantitative experiment, we show how the addition of small quantities (parts-per-million) of a flexible polymer to a Newtonian solvent dramatically affects both the onset conditions for this instability and the subsequent growth of the axial vorticity. Complementary numerical simulations with a finitely-extendible non-linear elastic dumbbell (FENE) model show that these modifications are due to the growth of polymeric stress within specific regions of the flow domain. Our data fills a significant gap in the literature between the previously-reported purely-inertial and purely-elastic flow regimes and provide a link between the two by showing how the instability mode is transformed as the fluid elasticity is varied. Our results and novel methods are relevant to understanding the mechanisms underlying industrial uses of weakly elastic fluids and also to understanding inertio-elastic instabilities in more confined flows through channels with intersections and stagnation points.

Friday 17:30 Ulisse

NF50

Onsager principle in viscoelastic flows

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Onsager principle is a variational principle that Onsager proposed as a corollary of his proof of his reciprocal relation [1]. It has been shown that many kinetic equations used in soft matter physics (Stokes equation for Newtonian fluid, diffusion equation, Ericksen-Leslie's equation for liquid crystals, and gel dynamic equations) can be derived from this principle [2]. Many viscoelastic models can also be derived from this principle [3, 4]. The principle is useful not only to derive such equations, but also to solve the equations in a simple way. Here we demonstrate this using an example of the bead-on-bead structure in viscoelastic fluids [5-7].

[1] Onsager, L. (1931). Physical review 37(4) 405 & 38(12), 2265. [2] Doi, M. (2013). Soft matter physics. Oxford University Press. [3] Beris, A. N. & Edwards, B. J. (1994). Thermodynamics of flowing systems: with internal microstructure. Oxford University Press. [4] Öttinger, H. C. (2005). Beyond equilibrium thermodynamics. John Wiley & Sons. [5] Entov, V. M. & Hinch, E. J. (1997) Journal of Non-Newtonian Fluid Mechanics, 72(1), 31-53. [6] Clasen, C. et al. (2006). Journal of Fluid Mechanics, 556, 283-308. [7] Zhou, J. & Doi, M., Dynamics of viscoelastic filaments based on Onsager principle (under review).

Friday 17:50 Ulisse

NF51

Jetting of weakly viscoelastic fluids: a study on polymer degradation in ROJER experiments

Susanna Formenti¹, Bavand Keshavarz², Jianyi Du², Gareth H. McKinley², and Christian Clasen¹¹Department of Chemical Engineering, KU Leuven, Heverlee, Belgium; ²Department of Mechanical Engineering, MIT, Cambridge, MA, United States

Complementary to the CaBER technique, the Rayleigh Ohnesorge Jetting Extensional Rheometer (ROJER) is able to probe the extensional response of low-viscous weakly viscoelastic fluids, which are widely encountered in applications such as inkjet printing or spraying. A recent study has also pointed out that the thinning dynamics of weakly viscoelastic jets are governed by a slightly different force balance compared to static capillary bridges. Hence, a scaling of $R \propto \exp(-t/2\lambda)$ has to be considered to determine the correct relaxation time in case of ROJER experiments, in contrast with the $R \propto \exp(-t/3\lambda)$ scaling classically employed in CaBER-type experiments. However, experimental results on dilute solutions of high molecular weight flexible polymers show even larger discrepancies between the relaxation times obtained from CaBER and ROJER experiments, which cannot be explained only by considering the different force balances. This paper introduces an experimental study focussing on a possible reduction of molecular weight due to the high shear rates that polymer chains are subjected to in the jetting nozzle. Choosing high molecular weight dilute solutions suitable for both ROJER and CaBER experiments allows to compare the relaxation times obtained from jetting rheometry with static capillary breakup experiments performed both on fresh solutions and samples recovered after undergoing the jetting process. Systematic changes in the relaxation times are correlated to a decrease in molecular weight in the solutions after jetting as determined through gel permeation chromatography. In particular for the highest molecular weights, relaxation times calculated from ROJER experiments show a significant reduction compared to CaBER experiments on fresh samples, while they match CaBER results obtained on the solutions recovered after jetting. This degradation phenomena will be related to critical stresses experienced in the nozzle.

Symposium CS

Colloids & Suspensions

Organizers: George Petekidis, Norbert Willenbacher and Emanuela Zaccarelli

Friday 14:20 Tritone

CS52

Rheology of suspension and particles interactions

William Chèvremont¹, Hugues Bodiguel¹, and Bruno Chareyre²

¹*LRP, CNRS, Univ. Grenoble-Alpes, Grenoble INP, Grenoble, France;* ²*CNRS, Univ. Grenoble-Alpes, Grenoble INP, 3SR, Grenoble 38000, France*

Suspension flows involves a wide range of phenomena which depends strongly on concentration, confinement and shear rate. Some suspensions show Newtonian behavior, but many of them also shows shear thinning and/or shear thickening. During this work, we study the influence of inter-particles interactions, and how they can modify suspension flow. End-term objective of this work is to tune the fluid properties in order to modify some phenomena like segregation, migration or clogging in a microchannel. Conventional rheometry measurement are done on suspensions of calibrated PMMA microspheres with many Newtonian fluids. Force measurement between particles are also done on those medium using an optical tweezers. Those measurements allow to determine the particles interactions, and so their microscopic behavior. The objective is to correlate these two measurements, in order to understand how the microscopic behavior can change the macroscopic one. On the other hand, suspensions are numerically simulated using a discrete element method. Simulations allows us to test a wide range of conditions and to vary some parameters that are hard to change on experiments. Secondly, simulations allows us to identify, quantify and characterize each phenomenon and its relative importance. At the end, simulation and experimental results are confronted. This allows us to validate the numerical model, and to explain the experimental phenomena. First simulations results using a minimal model composed of simple contact and friction law for solid particle interaction, and lubrication for the fluid interaction shows good agreement with experimental values and values available in literature. From this base, other inter-particles interactions, that are said to be at the origin of non-Newtonian behavior are introduced into our model.

Friday 14:40 Tritone

CS53

Effect of the soil organic carbon on the rheology of natural slurries

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²*Environmental, Biological, Pharmaceutical Science&Technology, University of Campania Luigi Vanvitelli, Caserta, Caserta 81100, Italy*

Fast landslides often occur after heavy rains that tend to saturate the soil that eventually loses stability. Rain may also wash the soil removing the so-called dissolved organic carbon (DOC), which is the most vulnerable fraction of soil organic carbon (SOC). In a previous work, we demonstrated that SOC content plays a role on the rheological behaviour of slurries and, in particular, both the viscosity and the yield stress decreases by reducing the amount of SOC. Yield stress and viscosity can affect the mud flow trigger and propagation, respectively. Our results were obtained on soil collected from a site (Cervinara, Campania, South Italy) involved in a catastrophic fast landslide. The original SOC (= 8.51 g/Kg) was selectively removed with specific chemical treatments and we observed that DOC was the key SOC fraction stabilizing the slurry microstructure.

In this work, we want to study the role of SOC with another kind of soil sharing with Cervinara soil a similar granulometry and mineralogy, but having never been involved in fast landslides. The soil was collected from a level ground not far from Cervinara (Camposauro, Campania, South Italy) with more than one order of magnitude larger SOC content (about 140 g/kg). The sample was subjected to the same chemical treatments to selectively remove different aliquots of SOC and preliminary results suggest that DOC removal is less effective. Rheological measurements were performed with a strain-controlled rheometer (ARES G2, TA-Instruments) equipped with a 4-blades Vane geometry. To exclude sample drying, the experimental cell was kept under a water-saturated environment by means of a solvent trap. To account for the effect of soil particle sedimentation, a specific fast experimental protocol is adopted. The effect of the DOC removal is studied also with granulometry tests.

Friday 15:00 Tritone

CS54

Surfactant controlled zwitterionic cellulose nanofibrils dispersions

Vincenzo Calabrese¹, Juan C. Muñoz-García², Valeria Gabrielli², Marcelo A. da Silva¹, Julien Schmitt¹, Janet L. Scott³, Jesus Angulo², Yaroslav Z. Khimyak², and Karen J. Edler¹

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The assembly of TEMPO-oxidised cellulose nanofibrils in water has been broadly investigated under different conditions (e.g. pH, [1] ionic strength, [1, 2] surfactants [3]). Interfibrillar interactions were enhanced upon screening of the surface charge, mediated either by acidification, [1] or salt addition, [2] resulting in fluids with strong shear thinning properties. In order to have a broader tunability range of the cellulose nanofibrils assembly we have developed zwitterionic cellulose nanofibrils (ZCNF) via functionalization of oxidised cellulose. The assembly of ZCNF aqueous dispersions has been characterized via transmission electron microscopy and small angle neutron scattering, revealing a fibril-bundle structure. The presence of surfactant in the dispersions was successfully employed to tune the ZCNF assembly. Upon addition of an anionic surfactant, electrostatic stabilization induces a transition from fibril-bundles to individualized fibrils resulting in a quasi-Newtonian fluid. On the contrary, upon addition of cationic surfactants, the dispersion undergoes charge neutralization leading to more flocculated dispersions with strong shear thinning

behaviour. In conclusion, the addition of surfactants provides a straightforward method to tune the rheological properties of these dispersions.

[1] Fukuzumi, H. et al. (2014). *Cellulose*, 21(3), 1553-1559. [2] Dong, H. et al. (2013). *Biomacromolecules*, 14(9), 3338-3345. [3] Crawford, R. et al. (2012). *Green chemistry*, 14(2), 300-303.

Friday 15:20 Tritone

CS55

Four-dimensional characterisation of microstructure and rheology in suspension flow

Stefan J. Gstoehl¹, Christian M. Schlepuetz², Joerg Laeuger³, Peter Fischer¹, and Erich J. Windhab¹

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The full volumetric microstructural evolution and the dynamic rheological properties of non-Brownian suspensions were not accessible synchronously so far. In this contribution we present a new setup that combines synchrotron μ CT with a co-rotating two-motor MCR 702. We use a 3D printed shear cell design to match the requirements for size, roughness, X-ray attenuation, and mechanical stability. We recover the full volumetric microstructure over time while measuring all relevant rheometric quantities. The dynamic structural information is acquired and an averaged velocity profile or single particle traces can be captured.

Friday 15:40 Tritone

CS56

Orientation dynamics of dilute graphene suspensions: dichroism and modeling

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¹*Chemical and Petroleum engineering, University of Calgary, Calgary, Canada;* ²*Chemical Engineering, University of Hasselt, Hasselt, Belgium;* ³*Chemical and Biological engineering, Princeton University, Princeton, NJ, United States;* ⁴*Material engineering, ETH Zurich, Zurich, Switzerland*

Graphene sheets are two-dimensional structures made of carbon atoms, which are electrically and thermally conductive and have unique mechanical properties. They have potential applications in many fields, including organic electronics, reinforced and electrically conducting composites and even new types of biological sensors and devices. Promising processing routes involve suspensions of graphene flakes. However, to fully exploit graphene suspensions, control of the microstructure evolution during flow is required. Specifically, the question is how (and if) these thin sheets tumble in transient shear flows or possibly fold and crumple during their motion. In this work, we analyse the orientation dynamics of graphene suspensions in the dilute regime by examining their rheo-optical response. Dichroism is obtained in a Couette flow geometry which allows direct measurement of the average orientation angle of the particles with respect to the flow direction. Micrometer sized and functionalized graphene flakes were dispersed in a Newtonian mineral oil. The orientation of the system is studied in simple shear flow at steady state and using large amplitude oscillatory shear (LAOS) as a prototype transient flows. In LAOS, the suspensions present an interesting double peaked response at large strains during oscillation. To explain flow behaviour of graphene suspensions in simple steady shear and in LAOS, the particles are modelled as oblate spheroids and the suspension orientation dynamics are captured by a single particle Smoluchowski equation. This simple model captures surprisingly well, especially given the strong approximation of particle shape, the suspensions dynamics without the need of additional fitting parameters and suggests the graphene flakes tumble as rigid plates.

Friday 16:30 Tritone

CS57

Aging and rheology of salt-free aqueous Laponite dispersions

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Laponite dispersions have been widely studied for their appealing industrial applications as well as for their interesting and peculiar properties. The anisotropy of the Laponite nanoparticles, combined with the competition between attractive and repulsive interactions originates the complexity of the phase diagram of such colloidal systems. Depending both on nanoclay and salt concentrations, different final arrested states (gel, repulsive or attractive glass) can be attained after quite different aging times. The present study concerns the aging evolution of salt-free aqueous dispersions with Laponite concentrations ranging from 0.33 to 2.0 % wt/wt. Rheological measurements were performed under linear and nonlinear conditions after different days from sample preparation, also in combination with Low-Field NMR relaxometry tests. The time evolution of the most significant rheological parameters (zero shear viscosity, yield stress and storage modulus) is similar for all the systems examined. The sigmoidal profiles of the individual data sets can be superposed onto a master curve through a double shifting procedure, using a proper coordinate frame. Accordingly, the effects of concentration on aging kinetics of Laponite dispersions are synthetically described by the asymptotical values of the rheological parameters and the characteristic induction time. Additionally Low-Field NMR tests were carried out to evaluate the dependence of the relaxation time (T_2) of the water hydrogens on Laponite concentration and its evolution with aging time and to recognize possible correlations between NMR relaxation and rheological parameters of nanoclay dispersions.

Friday 16:50 Tritone

CS58

A quest for a model of non-colloidal suspensions

Roger I. Tanner, Shaocong Dai, and Arif Mahmud

School of Amme, University of Sydney, Sydney, New South Wales 2006, Australia

For practical use in manufacturing it would be convenient to have a model, albeit approximate, of particle-laden materials (suspensions) that would not need large amounts of computing and/or experimentation in every case. There are now adequate models of the pure matrix fluid behaviour, but there are no such models for suspensions, especially for suspensions with large particles (non-colloidal suspensions). One of the obstacles has been the single-minded devotion to shearing motions; experience with the matrix modelling has shown that it is not possible to formulate widely usable models if only shear is considered. Here some results of

axially-symmetric elongational tests on suspensions are compared with shearing data, and differences emerge. Also, the dramatic effects of friction and particle roughness on suspension rheology need to be explored thoroughly; we found that roughness in spherical particles induces large increases in viscosity in both shear and elongation. Some suggestions for modelling suspensions using a modified Reiner-Rivlin rule based on these observations are presented.

Friday 17:10 Tritone

CS59

Effect of confinement in the field-induced aggregation of magnetorheological fluids

Keshvad Shahrivar¹, Jose R. Morillas¹, Elizabeth Carreón-González², and Juan de Vicente¹

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Effect of Confinement in the Field-induced Aggregation of Magnetorheological Fluids Magnetorheological (MR) fluids are dispersions of magnetizable particles in non-magnetic carrier fluids. In the absence of magnetic fields MR fluids typically behave as non-Brownian Hard Spheres suspensions. However, when an external magnetic field is applied the particles become magnetized and aggregate forming anisotropic structures oriented in the field direction. As a result of the formation of these structures, the MR fluids become strongly shear thinning and eventually, for appropriate particle volume fractions and field strengths, exhibit an apparent yield stress. MR fluids are currently used in a wide range of torque-transfer applications because their rheological performance can be externally controlled [1]. Currently, there is a great interest in enhancing the rheological characteristics of MR fluids. For this, a deeper understanding of the physical mechanisms behind aggregates formation is required. In this presentation, we investigate the two-dimensional aggregation kinetics of dilute non-Brownian magnetic suspensions in rectangular microchannels using video-microscopy, image analysis, finite element methods and particle-level dynamic simulations. Especial emphasis is given to carbonyl iron suspensions that are of particular interest in the formulation of MR fluids. We demonstrate that both suspensions follow a deterministic aggregation process. Furthermore, experimental and simulation aggregation curves can be collapsed in a master curve when using the appropriate scaling time as a function of only two dimensionless numbers: Lambda ratio and particle surface fraction. Finally, some correlations between the microstructural aggregation states and bulk rheological performance are highlighted.

[1] Shahrivar, K. et al. (2017). *Soft matter*, 13(14), 2677-2685.

Friday 17:30 Tritone

CS60

Numerical study of suspensions of deformable particles

Marco E. Rosti and Luca Brandt

Mechanics, KTH, Stockholm, Sweden

We consider a model non-Newtonian fluid consisting of a suspension of deformable particles in a Newtonian solvent. Einstein showed in his pioneering work that the relative increase in effective viscosity is a linear function of the particle volume fraction for dilute suspensions of rigid particles. Inertia has been shown to introduce deviations from the behaviour predicted by the different empirical fits, an effect that can be related to an increase of the effective volume fraction. We here focus on the effect of elasticity, i.e. visco-elastic deformable particles. To tackle the problem at hand, we perform three-dimensional Direct Numerical Simulation of a plane Couette flow with a suspension of neutrally buoyant deformable viscous hyper-elastic particles. The problem is solved in a fully Eulerian methodology. We show that elasticity produces a shear-thinning effect in elastic suspensions (in comparison to rigid ones) and that it can be understood in terms of a reduction of the effective volume fraction of the suspension. The effective volume fraction is a function of the particles deformation, and by using it, the effective viscosity of suspension with different Capillary numbers, viscosity ratios and volume fraction, can be collapsed to the standard Eilers formula usually used for suspension of rigid particle. Normal stress differences will also be considered.

Friday 17:50 Tritone

CS61

Rheological behavior of cellulose nanocrystals (CNCs) in molten polymers

Quentin Beuguel, Davood Bagheri, Charles Bruel, Jason R. Tavares, Marie-Claude Heuzey, and Pierre J. Carreau

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The rheological behavior of cellulose nanocrystals (CNCs) in polyethylene glycol (PEG) and in polylactide (PLA) was investigated. CNCs were obtained from sulfuric acid hydrolysis of wood pulp and supplied after a spray- drying process. Ultrasonication was used to break agglomerates and disperse CNCs in water for PEG systems and in N,N-dimethylformamide (DMF) for PLA systems. Then PEG or PLA was added to the suspensions at room temperature. The samples were subsequently dried and compression molded. Small amplitude oscillatory shear (SAOS) data of molten CNC/PEG and CNC/PLA nanocomposites are presented and the behavior of both systems is compared using the reduced complex viscosity and reduced elastic modulus as well as the apparent yield stress. Both nanocomposites exhibit a percolated network with threshold values of 0.15 and 0.5 vol% for the CNC/PEG and CNC/PLA nanocomposites, respectively. These results, the reduced SAOS data and the apparent yield stress values confirm that the dispersion of the nanoparticles is better and the interactions stronger in PEG compared to PLA. These effects are explained in light of thermodynamic considerations.

Symposium FP

Food, Pharmaceuticals & Cosmetics

Organizers: Bruno de Cindio, Pietro Matricardi and Mats Stading

Friday 14:20 Nettuno 1

FP17

Biodegradable microfluidic microparticles for simultaneous detection of counterfeit and deteriorated edible productsBurak Eral¹, Ivan Rehor², Willem Kegel², Wim Hennink², and Tina Vermolen²¹*Process and Energy, TU Delft, Delft 2628 CB, The Netherlands;* ²*University of Utrecht, Utrecht, The Netherlands*

In an era of globalized trade relations where food and pharmaceutical products cross borders effortlessly, consumers face counterfeit and deteriorated products at elevated rates. This manuscript presents multi-functional, biodegradable hydrogel microparticles that can provide information on the authenticity and the potential deterioration of the tagged food or pharmaceutical formulations. These microparticles integrate spatially patterned authenticity code with two sensors - one detects possible presence of pathogenic microbes through monitoring pH while a second identifies products stored above optimal temperatures via optical monitoring of the microparticle degradation. Particles were synthesized from a biocompatible polymer and a photoinitiator, dextran modified with 2-hydroxyethylmethacrylate (dex-HEMA) and riboflavin, respectively, using a continuous, high throughput method stop-flow lithography. The proposed synthesis approach also enables crosslinking with visible light bringing about additional flexibility to flow lithography. Model liquid and solid food and pharmaceutical products were successfully labeled with microparticles and the functionality of the sensors in aqueous solutions was demonstrated.

Friday 14:40 Nettuno 1

FP18

Evaluation of the fermentation and aging process of a traditional Eastern fermented product (miso) through its rheological characterizationAna P. Mansidão, Catarina P. Prista, and Anabela C. Raymundo*LEAF-Linking Landscape, Environment, Agriculture and Food, University of Lisbon - Instituto Superior de Agronomia, Lisbon, Portugal*

The growing consumer interest in healthier and/or special consumption behaviors together with curiosity for new diets, and the availability of new food and beverage brought by globalization, is transforming the food industry as we know it, and redefining the relationship between food, nutrition, and health. A focus of the modern food industry is now to develop Functional Foods, healthier and more flavorful. Among these, fermentations are time-honored methods of food processing. These processes are traditionally applied to pulses, resulting in a significant increase in their soluble fraction and digestibility and a decrease of toxic compounds, and thus increases their nutrition value and potential as Functional Foods. The present work is part of a project that aims the development of different high quality fermented products by ancient Eastern methodologies, more standardized and under controlled conditions, and based on Portuguese pulses and neglected crops. Miso is a fermented pulse paste traditionally made from tane-koji (rice inoculated with spores of *Aspergillus oryzae*), soybean, water and salt (directly added to the mashed grains). In this work two types of Miso were developed using soybean and grass pea: red miso, strongly umami and salty, with 10-12% salt, and 6-12 months of fermentation/aging; and white miso, sweeter and less salty, with 5-6% salt, and a shorter fermentation/aging (1-3 months). Aging kinetics of the different types of miso were followed, during 6 months, by a texture characterization (TPA) and linear viscoelastic behavior (SAOS). It was found that after 15 days of preparation, the firmness of the different types of miso drastically decreases. However, this reduction is more pronounced in the case of sweet grass pea miso. During the following six months of maturation, there are no significant changes in firmness. However, in terms viscoelastic components it is possible to establish an aging profile of this type of products, which may be extremely useful for industrial scale development.

Friday 15:00 Nettuno 1

FP19

Mixtures of soft colloids: study of the viscosity of protein-stabilised emulsionsMarion Rouillet¹, Paul S. Clegg², and William J. Frith³¹*Unilever & University of Edinburgh, Sharnbrook, United Kingdom;* ²*School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom;* ³*Unilever R&D, Sharnbrook, United Kingdom*

Emulsifying oil in a protein suspension is a common processing step in the food industry. Regardless of the protein concentration, not all the proteins will adsorb on the oil/water interface during the emulsification, and protein-stabilised emulsions are thus mixtures of protein-stabilised droplets and un-adsorbed proteins. In our systems, the proteins, being surface-active, have a tendency to form aggregates, and so can be regarded as soft particles, not unlike the droplets. Assuming both components are suspensions of soft particles creates a framework by which we can model the viscosity of mixtures. Soft colloids have been the focus of many studies in the last two decades, however the field still lacks a unifying definition of volume fraction of soft colloids, which is a crucial element when comparing and mixing several systems. In addition, little attention has been paid to the relative contributions of individual components to the rheological behaviour of colloidal mixtures, especially if the components are not hard spheres, as it is the case for our emulsions of interest. Our aim is to provide a predictive model of the viscosity of protein-stabilised emulsions. A first step is to characterise separately the viscosity of suspensions of purified protein-stabilised droplets, and of protein suspensions over a wide range of concentrations. These components are then combined to form mixtures of well-characterised composition and their viscosity is compared to a semi-empirical model. Sodium caseinate-stabilised emulsions are produced here using a high-pressure homogenizer. The resulting droplet radius is ~100 nm, while sodium caseinate naturally forms aggregates of radius ~10 nm. Rotational rheology is used to measure the viscosity of the suspensions of individual components and mixtures, and because most suspensions display a Newtonian behaviour, we consider the zero-shear viscosity to sufficiently describe the wide range of compositions of protein-stabilised emulsions.

Friday 15:20 Nettuno 1

FP20

Mechanisms of drying-induced particle formation in mixtures of dairy proteins: a multiscale approach

Luca Lanotte¹, Cécile Le Floch-Fouere², Françoise Boissel², Pierre Schuck¹, and Romain Jeantet²

¹*Science et technologie du lait et de l'œuf, STLO, Institut National de la Recherche Agronomique, INRA, Rennes, Ille-et-Vilaine 35000, France;* ²*STLO, Agrocampus Ouest, Rennes, France*

The production of milk powders involves nowadays a significant portion of the dairy industry. Due to its rich composition in terms of proteins and macromolecules, shedding light on the mechanisms characterizing the evaporation of milk is a scientific challenge and an industrial need at the same time. In this study, we use a multi-scale approach to investigate the separate roles of the two major milk protein components (whey protein isolates and native micellar caseins) on the drying of droplets with different whey protein to casein ratio. The evolution of the desiccation phases and the morphology of the samples are observed coupling mass measurements, optical/confocal microscopy and ultrasounds. Our outcomes highlight how the physico-chemical properties at the molecular scale significantly affect dried particle formation and their final shape and mechanical behavior. We show that the sol-gel transition governs the development of the particle skin in case of single dairy protein solution, regardless of the type. The case of the whey protein / micellar caseins mixes is discussed in a second time.

Friday 15:40 Nettuno 1

FP21

Modelling the viscosity of soft plant particles suspensions

Cassandra Leverrier, Gérard Cuvelier, Gabrielle Moulin, Giana Almeida, and Paul Menut

UMR Ingénierie Procédés Aliments, AgroParisTech, INRA, Massy, France

Apple purees are concentrated suspensions of non-colloidal (180 µm), non-spherical and highly deformable particles. These particles are delimited by a plant cell wall and filled by the continuous phase. Under stress or when the concentration of particles increases, they compress and their volume decrease, making it difficult to determine their real volume fraction and understand their rheological properties. In general, the rheological behaviour of plant particle suspensions is described by three concentration domains, usually modelled separately: a diluted domain in which the particles have little interaction (newtonian), an intermediate domain marked by the appearance of a network between the particles (yield stress fluid behaviour, characterized by an elastic modulus at low deformation which increases strongly with the concentration of particles) and a concentrated domain in which the particles are forced to deform to allow the flow. In this work, we propose a mean to access the apparent volume fraction of plant particles and a model describing the dependence of viscosity on concentration over a wide range of concentrations. The proposed model, adapted from the Mendoza model (Mendoza 2013), fits precisely to the experimental results obtained on apple purées of variable particle size distribution and on model suspensions reconstituted in several continuous phases. Model parameters reflect particle stiffness and asphericity. Finally, by combining confocal microscopy and 3D reconstruction, we were able to show that the volume of cells decreases only in highly concentrated suspensions. By direct observation within the sample, we thus prove the ability of the plant particles to compress and thus reduce their volume when the concentration increases. This work offers interesting prospects for the processed fruit and vegetable industry and has led to a step forward in the modelling of these systems.

Friday 16:30 Nettuno 1

Keynote FP22

Rheological design spaces for foods, beverages and skin care products

Jan Engmann

Institute of Materials Science, Nestlé Research Center, Lausanne 1000, Switzerland

Food research & development aims to characterise, control and design sensorially attractive products under given constraints (e.g. nutritional quality, regulation, cost of ingredients and manufacturing). The size of a rheological design space (deformations, stresses, length & time scales) determines the necessary instrumentation, measurement protocols and data analysis that are required, which all carry a cost. Hence, the size of the "rheological design space" needs to be optimised. Very similar considerations apply to other consumer products, e.g. skin care. The talk will discuss the nature and size of such rheological design spaces from different view points: (a) macroscopic characterisation, (b) product structure (from molecular to macroscopic/visible) and (c) interaction with the human body (sensation, oral processing, swallowing). Application of classical materials science approaches (e.g. the "Ashby method") will be evaluated, with a perspective how well rheological design spaces are currently captured in food rheology research.

Friday 17:10 Nettuno 1

FP23

Clustering of oil droplets in o/w emulsions: Methodologies to control cluster size and interaction strength

Philipp L. Fuhrmann¹, Guido Sala¹, Markus A. Stieger², and Elke Scholten¹

¹*Physics and Physical Chemistry of Foods, Wageningen University & Research, Wageningen, The Netherlands;*

²*Division of Human Nutrition, Wageningen University & Research, Wageningen, The Netherlands*

The spatial distribution of fat in solids influences mechanical and sensorial properties. Spatial inhomogeneity of fat in soft-solid foods, i.e. the presence of macroscopic fat enriched and depleted areas, influences mechanical properties by increasing gel strength. On a macroscopic scale (mm), spatial inhomogeneity of fat leads to an increase in creaminess perception. We hypothesise that clustering of oil droplets on smaller length scales (µm) alters rheological properties and sensory perception of emulsions. Currently, there is a lack of procedures allowing to steer controllably oil droplet cluster-size and -strength in emulsions. The aim of this study was to compare methodologies to cluster oil droplets and to investigate the effect of size and interaction strength on the rheology of emulsions. We compared the efficiency of chemically linking protein-stabilized o/w emulsions using polyphenols and heteroaggregation. For the hetero-aggregation, two emulsifiers (gelatine and DATEM) were used to create droplets with positive or negative surface charge. Those oppositely charged o/w emulsions were subsequently mixed in different ratios. Chemical cross-linking and heteroaggregation allowed to control cluster size and oil droplet interaction strength. By increasing cross-linker content

or varying mass ratio between oppositely charged emulsions, oil droplet clusters ranging from 2-150 μm diameter were obtained. The interaction strength, determined as critical strain, could be varied by changing charge density of emulsifiers. Large clusters increased the effective volume fraction of oil droplets by up to 5x compared to single-droplet emulsions, thereby increasing viscosity by over 100x while keeping oil content constant. We conclude that polyphenol-based chemical cross-linking and hetero-aggregation allow to control the structural rearrangement of oil droplets in emulsions. This may permit to reduce oil content in emulsion based foods without adding thickeners while maintaining oil related perception.

Friday 17:30 Nettuno 1

FP24

Bulk and interfacial rheology oil-in-water emulsions stabilised with different types of sugar beet pectin – sodium caseinate conjugates

Juyang Zhang¹ and Bettina Wolf²

¹Food Science, University of Nottingham, Sutton Bonington LE125RD, United Kingdom; ²Food Science Division, School of Biosciences, The University of Nottingham, Loughborough LE12 5RD, United Kingdom

The aim of this research was to test the hypothesis that the interacting mechanism of a mixed biopolymer system designed to stabilise the interface of an oil-in-water emulsion impacts on the interfacial rheological properties and, thus, the bulk rheological properties of this emulsion system. The chosen mixed biopolymer system was sugar beet pectin (SBP) and sodium caseinate (SC) at mixing ratios of SBP:SC of 1:1, 1:3 and 3:1. Physical and chemical conjugates prepared by electrostatic complexation near the isoelectric point of sodium caseinate, enzyme (laccase) catalysed oxidation and Maillard reaction, respectively, were included. Emulsions were then processed at pH 4.5, near the isoelectric point of sodium caseinate, via high shear overhead mixing followed by assessment for stability against coalescence, zeta potential and dynamic rheological properties of the emulsion cream phase. The different types of interfaces were replicated in a pendant drop tensiometer for dilatational interfacial rheological property analysis. All three types of SBP:SC conjugates, independent of mixing ratio, stabilised the emulsion interfaces well, i.e., the emulsions were stable against coalescence. Extensive flocculation was observed for the protein dominated Maillard based conjugates. Bulk and interfacial rheological data were affected by mixing ratio as well as type of conjugate. All emulsion cream phases and replicated droplet interfaces showed predominantly elastic behaviour, and where one conjugate type showed higher G' values, e.g. the enzymatic created conjugate at a mixing ratio of 1:1, compared to another one the trend was the same for E' . To include one observation here, the slope of G' versus frequency assessed in the linear viscoelastic domain revealed strongest gel-like behaviour for 1:3 electrostatic and Maillard based conjugates compared to a slight incline in G' versus frequency for all other systems. In the case of the Maillard based conjugate, this is related to the flocculated nature of the sample.

Friday 17:50 Nettuno 1

FP25

Bolus rheology during chewing of high protein extruded snack from pea flour

Magdalena Kristiawan¹, Guy Della Valle¹, Christian Salles², Valérie Micard³, Anne-Laure Réguerre¹, M.A. Emin⁴, and Christine Alchamieh¹

¹BIA, INRA, Nantes, France; ²CSGA, INRA, Dijon, France; ³SupAgro-INRA, Montpellier, France; ⁴Institute of Process Engineering in Life Sciences, 3Karlsruhe Institute of Technology, Karlsruhe, Germany

Pulse legumes (pea, lentil, faba bean) are excellent source of proteins (20-30% db), dietary fibers (10-30%), and starch (40-55%). The formulation of gluten-free extruded snacks made entirely from pulse legumes is an interesting way to introduce legumes to young people. Due to the reactivity of protein components under thermomechanical treatment, extrusion can produce cellular structures with various texture and starch-protein composite morphology. In turn, the morphology of parietal material governs masticatory performances. For the first time, the interaction coefficient between bolus and saliva was determined by taking into account multi-scale structure of high-protein solid foams. The pea flour was extruded using a twin-screw extruder to obtain solid foams adapted to human mastication. Some samples were selected for in-vitro chewing by mapping the main properties: density, cellular architecture, texture, water absorption index (WAI) of starch and solubility of protein aggregates linked by S-S bonds in the dithiothreitol (DTE) using Principal Component Analysis. The boluses were collected at 3 chewing steps, representing different chewing times (t) until swallowing. The size distribution of bolus fragments was determined by imaging technique. Bolus consistency and water ("saliva") uptake were determined by an adapted capillary rheometer, and gravimetric method, respectively. For all samples, the bolus viscosity exhibited shear thinning behaviour and it decreased with chewing time. Bolus flow index was quite constant for all chewing conditions and samples. However, bolus consistency index was correlated negatively to bolus water uptake (W) through a plasticization coefficient. Furthermore, W could be predicted from theoretical salivary flow and median particle size. The model parameters depending on foams absorption properties could be expressed in function of WAI and protein solubility in DTE. The results will enrich the database for mechanistic modelling of proteinaceous solid foams chewing.

Symposium IP

Industrial Rheology & Processing

Organizers: Paulo Roberto de Souza Mendes, Dino Ferri and Joao Maia

Friday 14:20 Nettuno 2-3

IP16

Filament breakup and satellite formation in the jetting of highly viscous dense suspensions for electronics applicationsGustaf E. Mårtensson¹ and Fabian Carson²¹*www.mycronic.com, Mycronic AB - Kungliga Tekniska Högskolan, Täby 18303, Sweden;* ²*R&D, Mycronic AB, Täby 18303, Sweden*

The controlled deposition of fluids by non-contact dispensing and jetting is important in various applications, including decorative printing, additive manufacturing, drug formulation and printed electronics. The jetting of rheologically complex dense fluid suspensions is particularly challenging and additional factors need to be considered, such as non-Newtonian and viscoelastic behaviour, volume fraction, as well as particle size, shape, roughness and hardness. In this study, we examine the filament formation and breakup process of high viscosity dense fluids. Using high-speed imaging, the dynamics of droplet formation and the occurrence of satellites can be observed. Solder paste is an example of a high viscosity dense suspension containing a mixture of micron-sized metal alloy particles and organic flux. The precise and repeatable deposition of solder paste onto printed circuit boards is at the core of surface mount technology that is used to prepare most electronic devices. The jet printing of solder paste requires that the fluid is deposited with high positioning and volume accuracy and repeatability, good shape and few satellite droplets. However, little is understood about satellite formation behaviour when jetting highly viscous dense suspensions. The jetting behaviour is a combination of the ejector dimensions, the fluid properties and the actuation profile. Studies utilising a high-speed camera imaging at or above 100 000 Hz allow the filament formation, deposition and breakup process to be visualized and connected to the jetting behaviour of a droplet ejected through a nozzle due to a rapid volumetric displacement of fluid. By following the drop formation process, we are able to describe the various formation mechanisms of satellites. Several factors that influence the formation of satellites, such as fluid ejection speed and filament break-off time, are identified and will be presented.

Friday 14:40 Nettuno 2-3

IP17

The reinforcement effect in well-defined segmented copolymers: counting the topological constraints at the mesoscopic-scaleGuilhem P. Baeza*MATEIS - UMR 5510, University of Lyon, INSA-Lyon, CNRS, Villeurbanne 69621, France*

Well-defined linear segmented block-copolymers made of a sequence of hard (T4T diamides) and soft (poly-tetrahydrofuran) units were melt-processed and characterized rheologically by using small amplitude oscillation shear (SAOS) measurements. Increasing the hard-segment (HS) content within the chains from 0 to 5, 10, 15 and 20 wt%HS was found to strongly enhance their plateau modulus, passing respectively from 1.7 to 3.2, 8.5, 13 and 30 MPa. After a brief review of the main models predicting such reinforcement in both homogeneous melts (rubber elasticity) and bi-phasic materials (hydrodynamics), we propose an alternative view based on a recent work describing their mesoscale structure. Starting from basic topological arguments, our approach lies on evaluating the volume occupied by an entanglement in the soft phase (V_e) and using it as a reference for counting the number of "stickers" (i.e. HSs) that an equivalent volume in the hard phase would have contained. In this way, the crystallites are seen as local densifications of the polymer network rather than independent fillers - providing satisfying predictions up to 15 wt%HS. Our model is then tentatively extended to the case of a confined soft phase with the aim to describe the modulus upturn generally observed in highly crystalline polymers.

Friday 15:00 Nettuno 2-3

IP18

Semi-crystalline polymers in additive manufacturingClaire McIlroy and Richard S. Graham*School of Mathematical Sciences, University of Nottingham, Nottingham, United Kingdom*

Additive manufacturing, commonly known as 3D printing, has the potential to revolutionise manufacturing processes, offering increased precision, mass customisation and sustainability. A fundamental understanding of the relationships between printing parameters, material rheology and mechanical properties is crucial for facilitating additive manufacturing production of structure-critical components and assemblies. The most common method for printing plastics is known as fused filament fabrication (FFF). This process involves melting a thermoplastic, followed by layer-by-layer extrusion, cooling and re-solidification. 3D printers can handle a diverse range of rheologically complex materials; in particular, semi-crystalline materials have the important advantage of biodegradability, essential for regenerative medical applications. However, studies quantifying how semi-crystalline materials behave under typical printing-flow conditions involving high shear rates, complex geometries and rapid temperature changes are limited. We employ a non-isothermal molecularly-aware model for FFF processing of a semi-crystalline polymer melt. We incorporate flow-enhanced nucleation, which relates the molecular deformation of the polymer with the enhancement of crystallisation. The deformation imposed by FFF is dominated by the deposition process, which involves a 90 degree turn, and causes the polymers to become highly stretched and aligned along the flow direction. This anisotropy combined with rapid inhomogeneous cooling results in a distinct gradient in the number of crystalline structures across the cross-section of the deposited filament. This morphology depends of both print temperature and print speed.

Friday 15:20 Nettuno 2-3

IP19

Fused deposition modeling with amorphous (glassy) polymersPeter Olmsted*Department of Physics, Georgetown University, Washington, DC 20057, United States*

Fused Deposition Modeling (FDM), also known as Fused Filament Fabrication (FFF) is one of the easiest methods for Additive Manufacturing. Successful FFF requires optimizing materials and processes, and unfortunately the mechanical properties (modulus, toughness, thermal stability) of FFF parts are often sub-optimal compared to their bulk counterparts. I will discuss recent and ongoing attempts to model this process based on molecular features, as part of a team involving experimentists and modelers to effect a multiscale modeling approach.

Friday 15:40 Nettuno 2-3

IP20

Rheological properties at non-isothermal melt-stretching process and its control by blend techniqueMasayuki Yamaguchi*Materials Chemistry Area, Japan Advanced Institute of Science and Technology, Nomi, Ishikawa 923-1292, Japan*

It is found that the addition of poly(isobutyl methacrylate) (PIBM) with low viscosity into isotactic polypropylene (PP) effectively enhances the drawdown force, defined as the force required to stretch a molten polymer at the nonisothermal condition, although shear viscosity is barely affected by the PIBM addition. The mechanism of this phenomenon is found to be attributed to prompt glassification of PIBM droplets deformed to the flow direction. After passing through the die exit, the deformed PIBM droplets behave as glassy fibers prior to the crystallization of PP matrix because of the rapid cooling, leading to the excess stretching force due to large shear deformation of the matrix PP located between the dispersed glassy fibers during stretching.

Friday 16:30 Nettuno 2-3

IP21

Capillary flow of HDPE melts filled with lamellar rigid micro-particlesFrancesco Baldi¹ and Francesco Briatico-Vangosa²¹*Dipartimento di Ingegneria Meccanica e Industriale, Università degli Studi di Brescia, Brescia 25123, Italy;*²*Dipartimento di Chimica, Materiali e Ingegneria Chimica, Politecnico di Milano, Milano 20133, Italy*

In this work, the capillary flow of high-density polyethylene (HDPE) melts filled with lamellar particles of talc was investigated both at high and low flow rates. Different talc contents (up to 12.5 vol.% in the melt) were considered. A capillary rheometer, equipped with cylindrical dies and operating at constant-piston-velocity, and a melt flow indexer, for ISO 1133 melt volume-flow rate (MVR) tests, were used to examine high (up to and beyond the onset of "melt fracture" phenomena) and low flow rates, respectively. From capillary rheometer tests, data of steady-state shear viscosity and die entrance pressure drops were measured, with two different die diameters, and related to the results from the MVR experiments. At high flow rates, the presence of lamellar particles of talc in the HDPE melt promotes: i) the suppression of "melt fracture" phenomena; ii) opposite effects on steady-state shear viscosity and die entrance pressure drops, namely a slight decrease and a pronounced increase for the former and the latter flow property, respectively, in the stable-flow region. MVR-data seem to be controlled by the extent of the localized pressure drops in the converging flow at the die entrance. The results are discussed by referring also to electron microscopy analyses on cryo-fractured surfaces obtained from the extrudates formed after the flow through the capillary.

Friday 16:50 Nettuno 2-3

IP22

Effects of mold surface treatment on flow behavior and flash formation in BMC injection moldingFrancesco Briatico Vangosa¹, Fabio Cortinovis², Francesco Baldi³, Massimiliano Bestetti¹, and Marta Rink¹¹*Dipartimento di Chimica, Materiali e Ingegneria Chimica, Politecnico di Milano, Milano, Italy;* ²*NTS S.p.A., Lallio, Bergamo, Italy;* ³*Dipartimento di Ingegneria Meccanica e Industriale, Università degli Studi di Brescia, Brescia 25123, Italy*

BMC is a highly filled, polyester-based thermoset composite, which can be processed by reaction injection molding. This process is characterized by short injection times and high mold temperature, in order to avoid crosslinking during the filling phase and foster it after filling, respectively. Further, to reduce the risk of void formation or charring, related to air or solvent entrapment during the process, the mold have to be equipped with complex venting and evacuation systems. The combination of low viscosities, due to high shear rates and temperatures, high pressures, related to flow in long, thin cavities, and high thickness venting systems promotes the formation of flashes, the removal of which requires expensive post-molding operations. In the present work, the main causes for flash formation during injection are examined, and the possibility of applying an appropriate surface treatment to reduce this phenomenon is investigated. To this aim, a prototype mold has been designed. A section of the mold has interchangeable surfaces that underwent different surface treatments. Further, this section is equipped with pressure and temperature sensors to assess the BMC flow behavior in real processing conditions. The mold was then used in a molding campaign, and data acquired during the molding operation were analyzed in combination with those from a fundamental rheological characterization of the BMC and information on the extent of flashing measured on the samples after molding. The analysis highlighted a significant effect of the surface treatments in reducing the flash extent, probably related to an increase of the resistance to flow in the thin area where flash occur. Surprisingly, no significant effect on flow is observed from data measured in the instrumented section of the mold. These observation suggest complex effect of the flow channel thickness, still under investigation.

Friday 17:10 Nettuno 2-3

IP23

Shear-induced conformational changes of flexible and semi-rigid engineering thermoplastics and their influence on crystallization

Behzad Nazari¹, Jiho Seo¹, Ralph H. Colby¹, Burke Beauregard², Scott T. Milner², Alicyn M. Rhoades³, and Richard P. Schaake⁴

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Brief intervals of shear flow at rates exceeding the reciprocal of the Rouse time of the longest chains create precursors that nucleate orders of magnitude more crystals and change the morphology from $\sim 30\ \mu\text{m}$ spherulites to far smaller $\sim 1\ \mu\text{m}$ crystallites. This flow-induced crystallization (FIC) at low shear rates builds with shearing time and eventually saturates. In contrast, at much higher stress levels that might occur in processing flows, a second morphology transition to shish-kebabs is observed when a critical shear stress ($\sim 0.14\ \text{MPa}$ for iPP) is exceeded. The shish-kebab transition is evident in subsequent oscillatory shear as a weak gel and as a sudden jump in the pressure needed to push the material through the die in capillary rheometry. Flow-induced crystallization is studied in detail for isotactic polypropylenes and poly(ether ether ketone)s representing flexible and semi-rigid polymers, and for Nylon6,6 representing a flexible polymer with strong hydrogen bonding, to see which aspects of FIC are universal to all polymers and which aspects are polymer-specific. The fact that the precursors are quite stable allows the sheared samples to be removed from the rheometer and studied extensively with DSC and optical microscopy, while annealing at elevated temperatures allows the study of precursor stability.

Friday 17:30 Nettuno 2-3

IP24

Crystallization of star polymers under shear flow

Jose Ruiz-Franco¹, John Marakis², N. Gnan³, P. Lettinga⁴, J. Kohlbrecher⁵, M. Gauthier⁶, Dimitris Vlassopoulos², and E. Zaccarelli³

¹Department of Physic, Università La Sapienza di Roma, Rome, Lazio 00185, Italy; ²Department of Materials Science and Technology, FORTH, University of Crete, Creta, Greece; ³CNR Institute of Complex Systems, Uos Sapienza, Rome, Lazio 00185, Italy; ⁴Laboratory for Soft Matter and Biophysics, University of Leuven, Leuven, Belgium; ⁵Laboratory for Neutron Scattering, ETH Zurich & Paul Scherrer Institut, Villigen, Switzerland; ⁶Department of Chemistry, University of Waterloo, Waterloo, Canada;

Controlling crystallization in soft colloidal systems represents a fundamental challenge for material design. Among different approaches for enhancing the crystal phase, there are evidences that the application of a shear flow may favour the formation of crystals [1, 2], thus representing a new method to verify the existence of crystal phases predicted in several soft colloidal systems. In our work we numerically investigate the crystallization of star polymers induced by the presence of a shear flow. Star polymers, i.e. polymer chains anchored to a common centre, represent a favourite model system in soft matter being characterised by a rich phase diagram, encompassing multiple crystal phases. We simulate star-polymers using two Molecular Dynamics approaches: the first is based on SLLD equations with Gaussian thermostat (MD-GAUSSIAN) and the second uses Dissipative Particle Dynamics thermostat (MD-DPD). The latter has the advantage to implicitly include the hydrodynamic effects of the solvent, which is neglected in the former approach. Our simulations show that a transition from fluid to solid occurs in both types of simulations but the crystals found are of different types, being bcc-like in MD-GAUSSIAN simulations and fcc-like in MD-DPD. Most interestingly, we find that in MD-DPD a two-step crystallization takes place from fluid to bcc and then to fcc, showing the occurrence of a crystal-crystal transition in simulations. This is in agreement with recent experimental results obtained with oscillatory shear flow, thus highlighting the importance of hydrodynamics in the crystallisation process under shear flow. Finally, we discuss what happens during the crystal-crystal transition by comparing our case with the recent work of Peng. Y et al. [3] on 2D crystallisation of microgel particles.

[1] Petekidis, G. et al. (2002). Physical review E, 66(5), 051402. [2] Ackerson, B. J. & Pusey P. N. (1998). Physical review letters, 61, 1033. [3] Peng, Y. et al. (2015). Nature materials, 14(1), 101.

Friday 17:50 Nettuno 2-3

IP25

Mutual effects of flow and crystallization: analysis of morphology development and hardening in a polypropylene

Roberto Pantani¹, Giuseppe Titomanlio², Vito Speranza³, Felice De Santis⁴, and Annarita De Meo⁵

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During processing of a semi-crystalline resin, a molten polymer flows at temperatures lower than the thermodynamic melting point. In most of cases the crystallization process takes place while the polymer is still flowing and this induces a dramatic change of rheological properties and sometimes an anticipated and unpredicted solidification. The description of the effects of crystallinity on flow is still challenging, mainly because of the difficulties in measuring simultaneously rheological properties and crystallinity evolution. Furthermore, the problem is complicated by the fact that crystallization rate increases by effect of flow, and thus the test itself modifies the material behavior. This is the other side of the phenomenon, which by itself is of great practical interest and is equally challenging: the so-called "flow-induced crystallization". The results of a series of investigations carried out at the University of Salerno by adopting an iPP, are organically summarized and a series of conclusions are drawn which allow to elucidate the correlations between flow and morphology development.

Symposium LA

Living & Active Matter

Organizers: Pietro Cicuta, Antonio De Simone and Gerhard Gompper

Friday 14:20 Nettuno 4

LA12

Theoretical rheology of active brownian particlesThomas Voigtman*Institute of Material Physics in Space, German Aerospace Center, Cologne, Germany*

We develop a theoretical approach to describe the nonlinear rheology of dense systems composed of active Brownian particles (ABP). ABP are a simple model for active fluids, characterized by their passive translational and orientational diffusion, and a fixed self-propulsion velocity. The collective dynamics of the system is characterized by various slow time scales that represent an interplay between active driving, the shear rate, and slow structural relaxation. Our theory is based on an extension of the integration-through transients (ITT) mechanism in combination with a mode-coupling theory of the glass transition, that has been successful already for passive dense suspensions. Using ITT, nonequilibrium transport coefficients are calculated, in particular the nonequilibrium "active" stresses and the coarse-grained density dependent swim velocity, a key quantity in understanding the nonequilibrium phase behavior of the active fluid.

Friday 14:40 Nettuno 4

LA13

Simultaneous pulsatile and vibratile flow of a human blood with cholesterol: analytical and numerical solutionsEdtson E. Herrera Valencia¹, Fausto Calderas¹, Mayra L. Sanchez Villavicencio², Luis Medina Torres³, and Octavio Manero⁴

¹Chemical Engineering, UNAM, Mexico City, Mexico City 08500, Mexico; ²Pharmacology Department, UAM IZTAPALAPA, Mexico City, Mexico City 08500, Mexico; ³Food, UNAM, Mexico City, Mexico City 04510, Mexico; ⁴Institute for Materials Research, National Autonomous University of México, Coyoacan, Distrito Federal 04510, Mexico

The paper presents theory and computer simulation of the rectilinear flow of a complex fluid (human blood) under a pulsating time-dependent pressure gradient is analyzed. A first approximation of the real case of blood flowing in a vein is described. The pressure gradient simulates the pumping work of the heart while the flow geometry (circular tube) is assumed rigid, smooth and cylindrical. The rheological behavior of blood with different cholesterol levels is modelled using the Bautista-Manero-Puig (BMP) constitutive equation. This constitutive equation contains an evolution term to account for structure modification (Fredrickson 1970; Bautista et al. 1999). It is written in terms of a structural parameter which depends on space and time, bounded by two characteristic viscosities: the zero strain-rate viscosity and the high-strain viscosity. This equation is coupled dynamically to a well-established non-linear rheological equation of state, the upper-convected Maxwell equation. According to the analytical solution, a flow enhancement is predicted to first order which represents the optimum pumping work of the heart which governs the flow of blood in the entire body. This work is a contribution to the understanding of the complex rheology involved in the discontinuous pressure driven flow of blood in the human body. The problem is motivated and can be applied to the modeling of oil recovery operations, bio polymers such as: (i) super fibres (spider silk), (ii) flexoelectric membranes (Outer Hair Cells) and (iii) research of new materials. The results are a contribution to the evolving fundamental understanding of the role of non-Newtonian effects in the areas of bio-rheology, biophysics, physiology and medical devices that operate through mechanical forces coupling with and fluid interactions

Friday 15:00 Nettuno 4

LA14

Characterizing the shear rheology of live endothelial cell monolayersAdaeze A. Undieh¹, Maria C. Merola², Juho Pokki¹, Ngan F. Huang³, and Gerald G. Fuller¹

¹Department of Chemical Engineering, Stanford University, Stanford, CA, United States; ²Life Science Division, Alcimed, Merle, Lyone 69003, France; ³School of Medicine, Stanford Cardiovascular Institute, Stanford University, Stanford, CA, United States

Vascular endothelial cells line the interior of all blood vessels in the body, forming a one-cell thick, mechanically-integrated monolayer (the "endothelium") in direct contact with mechanical stresses from blood flow. Blood fluid shear stresses are known to play a critical regulatory role in both normal and pathological vascular conditions; however, a mechanistic understanding of how the endothelium transduces external mechanical shear signals into biochemical responses is still elusive. Given that the mechanical properties of the endothelium determine how applied external forces are transmitted to subcellular structures, a quantitative understanding of endothelial rheology in normal and diseased states could shed light on the mechanical underpinnings of vascular disease. The Fuller Research Group previously developed a live cell monolayer rheometer (LCMR) that enables rheological measurements of adherent live cell monolayers using simple shear forces. In this work, the LCMR was used to mechanically characterize human microvascular endothelial cell monolayers under shear. Endothelial monolayers displayed viscoelastic solid-like behavior, as well as a strain softening response with increasing strain amplitude. To simulate the endothelium in a diseased state, endothelial monolayers were activated with TNF-alpha, an inflammatory cytokine previously observed in AFM studies to cause endothelial cell stiffening. Activated monolayers displayed increased peak shear moduli at all strains, as well as a change in the strain amplitude dependence of the peak modulus. The mechanical parameters measured in our system for normal and activated monolayers agree qualitatively with results from literature, suggesting the LCMR as a promising experimental approach for probing endothelium rheology in normal conditions and in disease.

Friday 15:20 Nettuno 4

LA15

Rheological response of cellular membranes in pulsed electric fieldsPouyan Boukany and Aswin Muralidharan*¹Chemical Engineering, Delft University of Technology, Delft, The Netherlands*

Living cells are permeabilized with electric pulses of high intensity enabling the transport of small and large molecules possible. This process, called electroporation (or electropermeabilization), allows hydrophilic biomolecules (such as anticancer drugs, RNA, and DNA molecules) to enter into cells. Recently, it has been shown that these pulses can destabilize cytoskeleton of the cell. However, the influence of the destabilization of cytoskeleton due to electric fields on the membrane mechanical properties is still unexplored. Deformation of membranes has been used in the past to estimate the membrane tension and bending rigidity. Here, we have first employed simplified model systems such as giant unilamellar vesicles (GUVs) to understand the electroporation mechanisms at the membrane level. We have investigated the role of gel-phase lipids in the electroporation response of binary GUVs (with different ratios). We have observed that the exposure to electric pulses leads to expel of fluid-phase lipids and concomitant decrease in GUVs size, whereas the gel-phase domains become buckled. Based on experiments and theoretical estimates of the pure fluid-phase and gel-phase GUVs, we have found that fluid-phase lipids can be expelled by the electrical forces and gel-phase lipids cannot. Moreover, our analyses suggest that the pore formation occurs primarily in the fluid-phase domains and that the pore size is similar in all GUVs containing fluid-phase lipids, irrespective of the gel-phase percentage. To unravel the role of electric field on the cytoskeleton during/after electroporation, we employ optical tweezers to measure the changes in the membrane properties after application of electric fields. We have found that application of electric fields on cells resulted in lower force barrier and tether force for membrane tube formation. Visualisation of stained actin after application of pulse indicated destabilization of actin network which may be the reason for the decrease in forces.

Friday 15:40 Nettuno 4

LA16

The mechanisms governing red blood cell aggregation. Implications for blood rheology.Giovanna Tomaiuolo, Antonio Carciati, and Stefano Guido*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

Human blood mechanical response is strongly affected by red blood cell (RBC) properties, such as volume fraction, deformability and aggregation. In particular, the tendency of RBCs to form packed structures plays an important role in blood flow behavior, causing the increase of blood viscosity, especially at low shear rates. It is well known that the formation of 3D structures made by trains of RBCs (rouleaux) is dependent on both the size of rouleaux and the cohesive forces within aggregates, usually expressed in terms of the shear stress required to disperse them [1]. Furthermore, RBC aggregation is promoted by the presence of plasma proteins, primarily fibrinogen, as well as the addition of macromolecules as dextran [2, 3]. Two main models have been proposed to describe RBC aggregation: the bridging model, based on the assumption that macromolecules as fibrinogen or dextran act as a bridge between two adjacent RBCs, and the depletion model, based on the gradient of osmotic pressure due to the presence of macromolecules in the suspending medium, leading to depletion interaction [4]. Nevertheless, the mechanism at the base of RBC aggregation is controversial and not yet fully elucidated. Here, we present a high-speed microscopy analysis of the kinetics of RBC aggregation as a function dextran concentration. We have observed that cell-cell aggregation is an increasing function of dextran, and that both the mechanisms (i.e. bridging and depletion) can coexist at certain dextran concentration. The effect of dextran has been evaluated on blood oscillatory response as well (Tomaiuolo et al., 2015).

[1] Chien, S. et al. (1983). *Annals of the New York Academy of Sciences*, 416(1), 190-206. [2] Ami, R. B. et al. (2001). *American Journal of Physiology-Heart and Circulatory Physiology*, 280(5), H1982-H1988. [3] Brust, M. et al. (2014). *Scientific reports*, 4, 4348. [4] Steffen, P. et al. (2013). *Physical review letters*, 110(1), 018102. [5] Tomaiuolo, G. et al. (2016). *Rheologica Acta*, 55(6), 485-495.

Friday 16:30 Nettuno 4

LA17

3-D tomography of blood flowChristian Wagner*Physics, Saarland University, Saarland 66123, Germany*

We propose a new confocal 3D imaging technique for fluorescent stained red blood cells (RBCs) in micro-fluidic flow. Our approach allows us to recover the full 3D representation of moving RBCs under conditions prevailing in the micro-vasculature. As key feature, we employ a micro-fluidic channel which is tilted by a small angle with respect to the objective. Image slices are then assembled to recover the volumetric representation of individual cells. In contrast to common scanning approaches, the present method relinquishes any mechanical actuation of the objective or stage and frame rates up to 600 FPS can be realized since no mechanical delay is involved. At maximum frame rate, cells up to a velocity of 1.5 mm/s can be recovered. In a micro-channel of $25\ \mu\text{m} \times 10\ \mu\text{m}$, we were able to find two equilibrium cell shapes under certain flow condition: the so called 'slipper' and the 'croissant' shape. Numerical simulations are performed which are in good agreement with experimental observations [1]. In larger channels, we use the confocal technique to characterize the margination of single rigidified RBCs in a suspension of healthy RBCs. Margination in blood is a phenomenon of great physiological importance and can have applications in cell separation and targeted drug delivery. Our confocal observation technique allows us to characterize the distribution of hard vs. soft cells in full time and space resolution for the first time and again numerical simulations are in good agreement although some quantitative differences remain that need further investigations.

[1] Quint, S. et al. (2017). *Applied Physics Letters*, 111(10), 103701.

Friday 16:50 Nettuno 4

LA18

The Newtonian behavior of whole blood in dromedary camelsUrsula B. Windberger¹, Roland Auer¹, Dina Baier², and Julian A. Skidmore³¹*Decentralized Biomedical Facilities, Medical University Vienna, Vienna, Vienna 1090, Austria;* ²*Institute of Cancer Research, Medical University Vienna, Vienna, Austria;* ³*Camel Reproduction Center, Dubai, United Arab Emirates*

Many of a species physical performances are oxygen dependent muscle activities, where an efficient oxygen supply to tissues directly translates into a physiological or competitive advantage over its prey, predators or competitors within the species. Mammalian blood has the capacity to lower whole blood viscosity (WBV) when shear stresses increase in narrow vessels. Consequently, cardiac workload and endothelial shear forces are reduced. The ability to adapt to high hemodynamic driving forces is based on the mechanical properties of red blood cells (RBC) and the quality of their integration into blood plasma. Since camelid RBC show unique properties this ability had to be investigated. Whole blood was collected from 10 dromedary camels, 4 Bactrian camels, and 10 horses. Blood from the dromedary camels and the horses was hematocrit adjusted and flow curves were measured at different temperatures to obtain the temperature- and HCT-dependency of WBV. Single cell spectroscopy on the Bactrian camel and horse RBCs was performed by AFM. Apparent Young's modulus as well as adhesion of RBCs were comparable between camel and horse. However camel whole blood was Newtonian at each HCT and temperature step, which was in contrast to horse blood that showed pronounced shear thinning, which further increases with the HCT increments. The ratio between cytoplasmic and plasma viscosity was high in camels, which might contribute to a low connectivity between RBCs and plasma, thus resulting in the Newtonian behavior of the blood suspension. This behavior might benefit the camel, since WBV will not increase at low blood flow velocity. However, at high shear rates, no flow enhancement will occur. The optimum HCT value, i.e. the ratio between HCT and WBV being at the maximum, for the camel blood was 29%, which is only slightly higher than the resting HCT of the animals. Conclusion: Camel blood appears to be optimized for low flow conditions. But increasing the HCT to boost the camels' performance during a race is highly questionable.

Friday 17:10 Nettuno 4

LA19

LAOStress studies of fibrin clots: The role of incipient clot microstructure in the nonlinear viscoelastic properties of fully formed fibrin clotsFruzina Lamer¹, Bethan Thomas¹, Daniel J. Curtis², Nafiseh Badiei², Karl Hawkins¹, and Rhodri Williams²¹*Medical School, Swansea University, Swansea, United Kingdom;* ²*College of Engineering, Swansea University, Swansea, Wales SA1 8EN, United Kingdom*

The nonlinear rheological properties of fibrin clots are important for understanding the mechanisms of embolism ("break off") of clots as a consequence of the haemodynamic forces encountered in blood vessels. We have recently demonstrated the application of large amplitude oscillatory shear (LAOStress) in characterising the nonlinear viscoelastic properties of fibrin clots over a wide range of shear stresses [1]. Alternating application of LAOStress and small amplitude oscillatory shear provide detailed information of reversible and irreversible structural changes of the fibrin network revealing several distinct regions of nonlinear viscoelastic behaviour up to the point of network fracture. In the present study, we investigate the relationships between the underlying microstructure of the fibrin network formed at the Gel Point, as characterised by a fractal dimension, with the nonlinear viscoelastic properties of the eventual (i.e. fully formed) network. The results show that fibrin clots formed from incipient clots with different values of fractal dimension (as manipulated by the addition of different levels of the enzyme thrombin) display markedly different nonlinear viscoelastic behaviour in terms of shifts in the aforementioned regions to different levels of applied stress. This work suggests that incipient clot microstructure influences the probability of the fully formed clot to break off due to haemodynamic forces and that the measurement of a fractal dimension may serve as a biomarker for predicting embolism in patients whom experience thrombosis.

[1] Lamer, T. F. et al. (2017). *Physics of Fluids*, 29(12), 121606.

Friday 17:30 Nettuno 4

LA20

Identification of the viscoelastic properties of human blood plasmaStylianos Varchanis¹, Yannis Dimakopoulos¹, John Tsamopoulos¹, and Christian Wagner²¹*Department of Chemical Engineering, University of Patras, Patras, Greece;* ²*Physics, Saarland University, Saarland 66123, Germany*

Blood plasma is a dilute water solution that contains proteins, hormones, etc. Many studies have assumed that it behaves like a Newtonian fluid. However, more recent experimental observations suggest that it exhibits significant viscoelastic effects [1]. Understanding the rheological response of plasma is of crucial importance as it is well-known that deviations of plasma's viscosity from normal values can indicate serious diseases. In addition, the viscoelastic character of the blood plasma should be taken under consideration, because it can have great impact on blood rheology [2]. We investigate theoretically the capability of a widely-used, multi-mode constitutive model for polymers (Giesekus) to predict inhomogeneous flows of plasma in (1) a capillary breakup extensional rheometer (CABER), using a 2D axisymmetric model and (2) a microfluidic contraction-expansion device, solving the full 3D transient governing equations. The results are in very good agreement with the experiments, because they predict important features of blood plasma's flow, such as the bead-on-a-string formation in CABER and the strain-rate viscosity thinning in the 3D flow. All these verify that blood plasma has indeed viscoelastic properties. In addition, based on the fit of the model to the inhomogeneous flows, we provide a full rheometric data set for blood plasma in homogeneous shear and elongational flows.

[1] Brust, M. et al. (2013). *Physical Review Letters*, 110(7), 078305. [2] Pranay, P. et al. (2012). *Physics of Fluids*, 24(6), 061902.

Friday 17:50 Nettuno 4

LA21

Investigation of red blood cell membrane deformability during agingGiuseppe Pesce*Dipartimento di Fisica "E. Pancini", Universita' Napoli "Federico II", Napoli, Italy*

Red blood cell (RBC) aging in health, disease and storage is of considerable interest. During aging/storage, RBCs lose water, 2,3-bisphosphoglyceric acid, ATP, proteins, Hb and vesicles leading to decreasing cell volume, surface charge and increasing density. As RBCs become aged, some surface materials, e.g. sialoglycoproteins- sialic acids, get sheared off and RBC structures/properties change. The deformability of RBCs plays crucially important roles in the main function of RBCs - oxygen transport through blood circulation. Holographic optical tweezers (HOT) is a powerful technique to manipulate microscopic objects without mechanical contact. Using HOT it is possible to stretch a RBC in a variety of ways: with two beads as handles attached to two opposite sides of the cell or even in more complex experiment using 6 or 8 beads to stretch the cell in many directions. Since the optical tweezers act as force transducer the elastic force of the membrane is directly measured. The RBC are collected at different stages of aging using the Percoll fractionation or the High speed centrifugation techniques.

[1] Hochmuth, R. M. & Waugh, R. E. (1987). Annual review of physiology, 49(1), 209-219. [2] Pesce, G. et al. (2015). JOSA B, 32(5), B84-B98. [3] Lenormand, G. et al. (2001). Biophysical Journal, 81(1), 43-56. [4] Yoon, Y. Z. et al. (2011). Soft Matter, 7(5), 2042-2051. [5] Seaman, G. V. F. et al. (1977). Blood, 50(6), 1001-1011.

Symposium EM**Experimental Methods & Progress in Rheometry**

Organizers: Christian Clasen, Salvatore Coppola and Qian Huang

Friday 14:20 Nettuno 5-6

Keynote EM8

Optimal Fourier transform rheometry for probing oscillatory rheology of complex fluids & gelsGareth H. McKinley¹, Michela Geri¹, Bavand Keshavarz¹, Christian Clasen², Daniel J. Curtis³, and Thibaut Divoux¹¹Mechanical Engineering, MIT, Cambridge, MA, United States; ²Department of Chemical Engineering, KU, Leuven, Leuven, Belgium; ³College of Engineering, Swansea University, Swansea, Wales SA1 8EN, United Kingdom

Measuring the viscoelastic spectra of time-evolving systems such as gels and thixotropic fluids requires signals that can provide both time- and frequency-resolution. Numerous methods have been proposed, including multi-wave techniques, random/white noise sequences and step-strain pulses. Here we focus on a technique that has been effectively used in radar/audio signal processing using an input signal known as a chirp with constant amplitude and continuously modulated frequency. Exponential chirps have been used in the past to determine the linear viscoelastic properties of gels and have been claimed to be "optimal". However, analysis reveals that spectral leakage in the power spectrum can compromise the precision of the measurements, especially when the signal length is decreased to improve time-resolution. Inspired by echolocation signals of bats and dolphins, we modulate the amplitude of the chirp with a specific choice of envelope and show that this dramatically reduces the error due to spectral leakage. We optimize the time-frequency bandwidth of the envelope modulation and show that the resulting Optimally Windowed Chirp (OWCh) waveform can be used to extract linear viscoelastic moduli with both time- and frequency-resolution and minimum error. Using this new technique, we study the acid-induced gelation of a protein solution. This approach enables us to measure the evolution in the elastic and loss moduli during gelation and shows that the linear viscoelastic response of the gel can be accurately measured over two decades of frequency using a test signal of just 15 seconds in length. A numerical model of the gelation process shows how the fidelity of the viscoelastic measurements depends on the time-frequency bandwidth of the input waveform and a dimensionless mutation number that characterizes the gelation rate. Finally, we discuss the sources of error in windowed chirp signals and provide scalings for the error magnitude as a function of a single dimensionless parameter characterizing the window length.

Friday 15:00 Nettuno 5-6

EM9

Electrical breakup rheometry of biofluids in oil submersionErwin Reichel¹, Gottfried Gamsjäger¹, Bradt Elke², Milan Kracalik², and Thomas Voglhuber-Brunnmaier¹¹Microelectronics and Microsensors, Johannes Kepler University, Linz, Austria; ²Institute of Polymer Science, Johannes Kepler Universität Linz, Linz, Austria

Biological fluids can have a significant content of polysaccharides with high molecular weight and therefore exhibit pronounced elasticity and extensional viscosity. A limited selection of instruments is available to investigate these properties, capillary breakup rheometry is the most widely used. We aim at measuring the elastic modulus and extensional viscosity of synovial fluid to quantify the concentration and molecular weight of hyaluronic acid in physiological samples, currently obtained from animals. The limited amount of available volume and the instability in contact with air is approached with the newly developed method of capillary breakup using an electrical field in oil submersion. The low viscous silicone oil has the dual function of preventing oxidation of the biofluid and electrical insulation of the high electrical fields. The filament forms under the action of electrostatic forces on charges influenced by a programmable high voltage source. Therefore, no moving external parts are required and the filament stretching forces can be tuned very finely. The formation and breakup is observed using high speed imaging and reference experiments using the Haake CaBER instrument, classical and microrheology. Furthermore a numerical analysis is carried out to investigate the potential of the method. From the experiments, a clear influence of the elasticity on the filament formation could be observed, which can be linked to reference measurements. We are therefore confident, that the proposed electrical breakup rheometer offers an interesting new measurement option, especially, when only lowest sample volumes are available or oxidization of the sample has to be avoided.

Friday 15:20 Nettuno 5-6

EM10

A new filament stretching device and the exploration of its capabilities and complementarity to existing techniques

Jasper Van Aeken¹, Taisir Shahid², Evelyne Van Ruymbeke², Peter Van Puyvelde¹, and Christian Clasen¹

¹*Chemical Engineering, KU Leuven, Leuven, Belgium;* ²*Institute of Condensed Matter and Nanosciences, University Catholique de Louvain, Louvain-la-Neuve, Walloon Brabant 1348, Belgium*

The determination of extensional flow properties of complex fluids is a challenging task, and only recently instruments have been commercialized to quantitatively investigate extensional material properties. For higher viscous systems, this includes filament stretching devices as SER and EVF fixtures or the VADER, which are usually limited in the maximum applicable strain and rates which they can probe. For lower viscous fluids capillary thinning devices as CaBER or contraction flows can act as indexers that are, however, not capable of applying defined deformation rates or strains. In this light, we want to present in this paper a novel filament stretching device that is capable of delivering constant strain rates that are sufficiently high to measure intermediate viscous systems that have capillary thinning and breaking time scales that are not accessible with current filament stretching devices. In this paper, the working principles of the newly built device are introduced and the operating limits explored with a set of Newtonian PDMS test fluids covering several orders of magnitude in viscosity as well as PIB based Boger fluids. The extension rate and strain limits are compared for the same sample fluids with results of a VADER as a benchmark for a state-of-the-art filament stretching device. The first objective of this paper is to validate the newly built set-up by this comparison and explore the limitations of the hardware components and accuracy. This is coupled to the optimization of the instrument control and software development with a focus on optimal control loop design. A second objective of this paper is then to identify the limits of the available devices and to demonstrate their complementarity and the possible parameter space that is now available to be explored.

Friday 15:40 Nettuno 5-6

EM11

"Stretching" the operating boundaries of SER: extensional characterization of branched polybutadiene beyond 4 Hencky strain units

Salvatore Coppola¹, Daniele Parisi², Federico Sebastiano Grasso³, and Fabio Bacchelli³

¹*Research Department, Versalis S.p.A., Ravenna 48123, Italy;* ²*Department of Materials Science and Technology, FORTH-University of Crete, Heraklion, Greece;* ³*Technical Management, Versalis SpA, Ravenna 48123, Italy*

Applying an extensional flow is a very effective tool for characterizing polymer melts as well as for assessing their processing features. It is in fact also strongly related to entrance pressure and to the possible occurrence of upstream instabilities during extrusion. One of the most popular devices to characterize extensional response is Sentmanat Extensional Rheometer (SER). This tool became very popular over the years because of the possibility of imposing, at least in principle, a constant and uniform Hencky strain. SER is also easy to use and requires a rather limited amount of sample. However, it has recently been shown by some research groups that SER has some limitations. One of this is related to the common use of flat specimens as such geometry does not ensure a real uniform, uniaxial extensional flow field in the sample. Another issue is related to the fact that, with flat specimens, a geometrical upper limit of Hencky strain is present which does not allow in most cases to overcome 4 strain units. This can be a problem e.g. when investigating long chain branched polymers having broad molar mass distribution as these polymers typically achieve very large strains at break. Furthermore, investigating the response up to large strain is extremely useful for elucidating effects of different polymer architectures. In this work, using fiber specimens, we adopted a simple procedure to overcome such upper limit of Hencky strain. We were able to characterize with SER the extensional response up to 6 Hencky strain units. As expected based on previous results of our and other groups, we observed strong differences between experimental results obtained with flat and fiber specimens. We show that only with the adopted procedure and using fiber specimens, we were able to fully characterize the extensional response of a set of long chain branched polybutadiene samples. Eventually, we also compared our experimental results with linear and quadratic molecular stress function theory (MSF) predictions.

Friday 16:30 Nettuno 5-6

EM12

On the role of the initial sample geometry in the extensional behaviour of a LDPE melt

Zdenek Stary¹ and Teodor Burghilea²

¹*Institute of Macromolecular Chemistry AS CR, Prague, Czech Republic;* ²*Laboratoire De Thermique et Energie de Nantes, Nantes, France*

A systematic experimental investigation of the role of the initial sample geometry in the extensional behaviour of a LDPE melt is presented using a Muenstedt tensile rheometer. The extensional behaviour of various cylindrical samples with different initial sizes (diameters and aspect ratios) is investigated using both traditional integral measurements of the tensile stress and local optical measurements of the geometric homogeneity of the samples during the tensile tests performed at constant Weissenberg number, $Wi=55$. Within this extensional flow regime, a local maximum of the tensile transient tensile stress was observed regardless the initial geometry of the sample. However, the Hencky strain at this maximum and the corresponding tensile stress are found to systematically depend on the initial geometry of the sample. A simple physical model explaining this experimental finding is proposed.

Friday 16:50 Nettuno 5-6

EM13

Some experimental pitfalls in measuring viscosity of Ionic LiquidsPatrick Rohlmann¹, Mark W. Rutland², and Sergei Glavatskih³¹*System and Component Design, KTH Royal Institute of Technology, Stockholm, Sweden;* ²*Surface and Corrosion Science, KTH Royal Institute of Technology, Stockholm, Sweden;* ³*System and Component Design, KTH Royal Institute of Technology, Stockholm, Sweden*

Ionic liquids (ILs) are salts which are in their liquid phase at temperatures below 373 K. These molten salts consist of anions and cations, which can be of different elemental compositions and structures. The theoretical possible number of different ILs is estimated to be 10^{18} . This diversity enables the way to design liquids with properties desired for specific applications. Viscosity is a key transport property. Therefore, systematic studies of different IL classes are desirable to find correlations between their chemical structure and their rheological properties. The present study provides a better understanding of how different molecular structures and compositions affect rheological properties of no-halogenated ILs over a large range of temperatures. More importantly our study demonstrates how to avoid some experimental pitfalls to obtain reliable viscosity data.

Friday 17:10 Nettuno 5-6

EM14

First and second normal stress differences in polymer fluidsSalvatore Costanzo¹, Giovanni Ianniruberto², Giuseppe Marrucci², and Dimitris Vlassopoulos¹¹*Department of Materials Science and Technology, FORTH, University of Crete, Crete, Greece;* ²*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

We present a simple and robust method to measure the viscosity and both the first and second normal stress differences of polymers in nonlinear shear flow. It is based on the use of cone-partitioned plate (CPP) geometry in order to measure over a wide range of shear rates without edge fracture problems. We employ a modular CPP setup with two different diameters of the inner transducer, mounted on a rotational strain-controlled rheometer. This setup overcomes limitations of previous approaches based on CPP, such as moderate temperatures and the need for multiple measurements with different volumes of samples, and yields data over a wide temperature range by performing a two-step measurement on two different samples. We present data obtained with two entangled polystyrene solutions at elevated temperatures, which compare favorably with the limited data available in the literature. Importantly, they compare well with predictions obtained with a recent tube-based model of entangled polymers accounting for shear-flow-induced molecular tumbling. We briefly discuss preliminary data with architecturally complex polymers in an attempt to link molecular structure to nonlinear elasticity. Limitations and possible improvements of the proposed simple experimental protocol are also discussed.

Friday 17:30 Nettuno 5-6

EM15

Partitioned plate arrangement: a rheological tool to characterize reactive polymersThomas Preveille¹, Dirk J. Dijkstra¹, Mathias Matner¹, Wilhelm Oppermann², and Diethelm Johannsmann²¹*Covestro AG, Leverkusen 51365, Germany;* ²*Institute of Physical Chemistry, Clausthal University of Technology, Clausthal Zellerfeld 38678, Germany*

Understanding the rheological behavior of thermoplastic polyurethane (TPU) melts is of critical importance for a wide range of applications including, for instance, additive manufacturing. The conventional plate-plate arrangement for SAOS has a problem when applied to aliphatic TPUs. At temperatures of $T = 180 - 240$ °C, an elastic, insoluble material forms at the rim of the plates, introducing artifacts into the measurement. The partitioned plate is a modification of the plate-plate tool, in which only the central portion of the plate is coupled to the transducers. It thus enabled us to observe the structural changes of the TPU bulk over time at high temperatures. In the case of aliphatic TPUs, two main reactions were observed. On the one hand, the reversible opening of the urethane bonds reduces the molecular weight (and decreases the viscosity, in consequence). On the other hand, allophanate formation induces chain branching (resulting in an increase in viscosity). Using the partitioned plate, we investigated the rheological behavior of aliphatic TPU melts, enabling thus a better design of the processing parameters. Besides TPU melts, the partitioned plate tool allows the characterization of other reactive systems which undergo reactions at the rim of the sample.

Friday 17:50 Nettuno 5-6

EM16

On the use of a new Shear-Induced Polarized Light Imaging (SIPLI) technique

Joerg Laeuger and Loredana Voelker-Pop

Anton Paar Germany, Ostfildern, Germany

Rheological methods reveal information on macroscopic material properties. However, the mechanical material properties are strongly dependent on the underlying microstructure. Therefore information on the microstructure is often valuable for a better understanding of the rheological behavior. Simultaneous use of rheological and optical techniques, i.e. of rheo-optical methods, is helpful to gain a better understanding of the dependencies between the microstructure and the mechanical properties of complex fluids. Different optical methods such as small angle light scattering, microscopy (polarized, fluorescence, confocal), spectroscopy (NIR, IR, Raman), birefringence and dichroism, as well as pure visualization techniques have been employed. In this paper, applications of a new rheo polarized imaging techniques will be discussed [1]. SIPLI (shear induced polarization light imaging) combines a visualization technique with measurements of local stresses through the detection of the birefringence. By employing parallel-plate geometries, different shear rates are existing throughout the sample, from a maximum shear rate at edge of the sample to a zero shear rate in the center of the plate. With SIPLI the whole plate is observed and the birefringence can be displayed over the full range of shear rates within one single experiment. Applications of the method are presented including simultaneous SIPLI and the rheology of the oriented lamellar phase of block copolymers, liquid crystals, cellulose and block copolymer solutions, as well as a study of the thermally-induced reversible transformation of worm-like micelles to spherical micelles. In addition, a direct relation

between the shish formation and the polymer melt viscosity upturn during flow-induced crystallization of semicrystalline polymers is demonstrated.

[1] Mykhaylyk, O. O. et al. (2016). Journal of Polymer Science Part B: Polymer Physics, 54(21), 2151-2170.

Poster Session

Symposium PO

Poster Session

Organizers: Claudia Carotenuto, Rossana Pasquino and Giovanna Tomaiuolo

Wednesday 18:10 Foyer Sirene

PO1

Behaviour of a ferrofluid droplet under the combined effect of a uniform magnetic field and a simple shear flow

Paolo Capobianchi, Marcello Lappa, and Mónica S. N. Oliveira

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Deformation of droplets has implications in a large variety of industrial and scientific applications. In the present work we investigate numerically the mechanism of deformation of a two-dimensional ferrofluid droplet surrounded by a second immiscible and non-magnetizable phase, subjected to the combined action of a simple shearing flow and a constant magnetic field applied in a direction perpendicular to the imposed shear. While the external flow forcing acts to deform and change the orientation of the droplet by virtue of viscous effects, the mismatch of magnetic stresses at the fluid-fluid interface tends to stretch the droplet along the direction of the magnetic field. The final flow configuration stems from the competition among these concurrent effects and the restoring influence of the interfacial tension force, which acts to maintain the droplet spherical. The problem is solved in the framework of a moving-boundary method based on the solution of the Navier-Stokes equations complemented with the additional equations required for describing the magnetic force. The results reveal interesting changes in the trends displayed by the droplet, in terms of deformation and inclination angle, as a function of the capillary number for different intensities of the applied magnetic field, while maintaining flow conditions corresponding to the Stokes regime. Precise analytical relationships are determined to describe such dependences. The mechanism of droplet relaxation from equilibrium when the magnetic force is suddenly removed is also investigated. According to our numerical experiments the deformation evolves in time following a harmonic decaying process, which, in the limit of small capillary number, i.e. for very small deformations, can be fairly well represented by the temporal evolution of a simple damped harmonic oscillator.

Wednesday 18:10 Foyer Sirene

PO2

The change of colloidal dynamics in wide range of volume fractions by tuning the softness of wax particles

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Emulsions are largely present in our daily life such as foods, cosmetics, pharmacy, painting, etc. In industrial applications of emulsion, the properties of this complex system are of interest. Unlike the suspension, emulsion could reach high volume fraction over the random close packing (RCP) volume fraction because of its deformable surface. Many studies tried to analyze the difference of bulk mechanical properties caused by microscopic surface changes in emulsion and suspension. Because hard particle suspension are regarded as having non-deformable surface, comparison between suspension and emulsion is usually done under RCP. In this presentation, 1-eicosene wax dispersed in water is used to enlarge the range of the comparison in terms of volume fraction. 1-eicosene has melting point at 24.6°, so at high temperature, the system acts as an emulsion. In contrast, decrease of temperature under melting point causes wax particles to solidify, making them behave as hard particles, which means the system is changed from emulsion to suspension without affecting system's basic properties except particle softness. Here, the 1-eicosene wax particle system over wide range of volume fraction was investigated using DWS for microscopic behavior and rheometer for macroscopic analysis. From 10~30 vol%(low regime), emulsion acts as a Newtonian fluid and the suspension's storage modulus follows power-law behavior. For 30~rcp vol%(intermediate regime), diffusion coefficient drops for suspension but gives no change for rheological behavior. Over rcp vol%(high regime) suspension's G' is size independent for the entire volume range while the emulsion is still scaled by Laplace pressure. At the critical volume fraction, for suspension there is a sudden jump for G' compared to a smooth increase for emulsion state. Comparing emulsion and suspension over a wide range of volume fractions, we suggest the systems' microstructure and the bulk physical properties at high volume fractions never studied before.

Wednesday 18:10 Foyer Sirene

PO3

Boundary conditions of foam flow are not frame invariant

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Time-dependent rheology and yield stress go hand in hand in most complex fluids. However, stable foams are one of the rare examples of yield stress fluids exhibiting no thixotropy, which makes them an ideal platform for studies of yielding-unyielding transition i.e. jamming [1]. Here, we study the behavior of foam in a 2D Hele-Shaw cell with an obstacle that creates a perturbation [2]. To change the boundary conditions, we perform two different experiments: 1) we make the foam flow past the obstacle and 2)

we move the obstacle through the foam (intruder). This gives us the possibility to assess the significance of the boundary conditions in the experimental set-up. In both experiments we find a negative wake behind the obstacle, in addition to flowing foams, also familiar from bubbles rising in viscoelastic fluids [3]. However, despite we use the same driving velocity in both experiments, the intensity of the wake varies between the two boundary conditions breaking frame invariance. We conclude that the drag of the cell's top and bottom plates significantly impacts the movement of the bubbles making them less mobile in the intruder experiment.

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Wednesday 18:10 Foyer Sirene

PO4

Electrical-rheological measurements on polymer blends containing preferentially localized carbon black

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Heterogeneous polymer blends filled with conductive filler often show preferential distribution of the filler particles in one of the blends components or at the interface. In this contribution the effect of the blend composition and localization of the carbon black on the rheological and electrical properties is discussed using the results from the simultaneous electrical-rheological measurements. Furthermore, the effect of the filler migration between the phases during the melt processing on the blends morphology is investigated.

Wednesday 18:10 Foyer Sirene

PO5

Engineering yield-stress fluids: high extensibility and direct write printing

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We report yield-stress fluids with high extensibility, behavior completely outside the standard paradigm of model materials which also violates standard constitutive equations for these materials [1]. Real materials including a printing resin, a direct-write 3D printing ink, chewing gums, and food products have a yield stress but are able to survive extremely large extensional deformations, well beyond what is possible for the most heavily studied 'model' materials including aqueous microgel particle suspensions (Carbopol), and aqueous clay suspensions (Laponite and Bentonite). We generate a design space for material selection and design of extensible yield-stress fluids and introduce model materials with this important behavior. To engineer (design) these fluids, we flip the typical structure-to-rheology analysis to become the inverse: rheology-to-structure with multiple possible materials as solutions [2]. We describe a specific case study of designing a particle-free emulsion with a yield stress and high extensibility used as a direct-write 3D printing ink which successfully patterns at filament diameters below that of any other known material [3].

[1] Nelson, A. Z. et al. (2018). *Journal of Rheology*, 62(1), 357-369. [2] Nelson, A. Z. & Ewoldt, R. H. (2017). *Soft matter*, 13(41), 7578-7594. [3] Rauzan, B. et al. Particle-free emulsions for 4D printing elastomers, in preparation.

Wednesday 18:10 Foyer Sirene

PO6

Effect of emulsion rheology on the flow restart of a well

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The water fraction (WF) increase in a well that operates by gas lift lead to a hardship on flow restart after long downtimes. Such behavior was observed after the WF reached 45%, condition in which all the water content is emulsified in oil. Rheological characterization has indicated the existence of a yield stress for the evaluated fluid. The paraffinic nature, associated with fluid WF increase and temperature below wax appearance temperature (WAT) implies in the yield stress observed. Besides yield stress measurements, rheological studies were conducted in order to assess emulsion to gas hydrate suspension transition. The results indicate that within the experimental time, there was no hydrate suspension formation, which reinforces the hypothesis of emulsion gelation. The experimental evidence of high yield stress of the produced fluid lead to an operational procedure change for subsea flowlines cleaning and well restart, minimizing the risk of flowline clogging and well downtime.

Wednesday 18:10 Foyer Sirene

PO7

Effect of normal stresses on the evolution of droplet shape during flow

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In the present work we are focusing on the large deformation of polymer blends composed of non-Newtonian droplet in a Newtonian matrix. The model of Yu, Bousmina, Zhou and Tucker (YBZT model) [1] was implemented and validated. This model is based on the general solution for creeping flow around a spherical droplet. While the YBZT model is a small deformation model, the constrained volume (CV) model is inherently a large deformation model, which was originally developed for droplets immersed in a matrix at a viscosity ratio of unity [2]. The model is then adapted for cases where the viscosity ratio is non-unity. We suggest that normal stresses that arise in the non-Newtonian droplet phase during flow cause secondary flow inside the droplet. We describe the non-Newtonian character of the fluid composing the droplet phase using the Giesekus model. Furthermore, we adjust the CV-model's description for the velocity gradient inside the droplet by adding a phenomenological term to describe this secondary flow, preceded by a fitting parameter that we call the pre-flow parameter. The value of this parameter is chosen by matching predictions of the

deformation parameter of the YBZT model during startup of shearing flow at the condition of non-Newtonian droplet phase to predictions of the non-Newtonian CV model. The non-Newtonian CV model is then compared against "intermediate" deformation results of Lerdwijitjarud et al. [3], and against large deformation results of Li and Sundaraj [4]. The comparison to Li and Sundaraj data shows that at certain conditions, the new non-Newtonian model is able to show droplet shape elongation in the vorticity direction.

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Wednesday 18:10 Foyer Sirene

PO8

Relationship between bulk and interfacial shear rheology of emulsions stabilised by legume protein from *Vicia faba* L

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Proteins are widely used in food products due to their ability to reduce interfacial tension and to form an interfacial film which prevents destabilization phenomena (i.e. droplet coalescence). The microstructure of food products has been typically studied considering macroscopic properties (i.e. bulk rheology) and microscopic techniques (i.e. droplet size distribution, CLSM or light microscopy), which has long been used to predict emulsion stability. On the other hand, emulsion formation and stabilization has been widely studied by analysing the interfacial properties of the complex fluid-fluid adsorbed layers formed. Thus, interfacial shear rheology is currently being regarded as a powerful technique, fostered by modern high-sensitive rotational rheometers, which may offer a high potential in the prediction of emulsion stability. The ability of legume proteins to achieve stable emulsions has been previously assessed using bulk rheology (from soya, pea or chickpea) and interfacial rheology (from chickpea). The objective of this work is to analyse the relationship between interfacial rheology and bulk rheology of emulsions stabilised by faba bean protein as a function of pH, as well as their link to emulsion microstructure and stability. Interfacial SAOS rheology was studied by means of a double wall-ring geometry fitted to a DHR3 rheometer (TA Instruments). Emulsions were prepared using a high-pressure homogenizer EmulsiFlex-C5 (Avestin). Further SAOS tests were carried out on emulsions with an AR-2000 rheometer (TA Instruments) using serrated plate-plate geometry. The results obtained show a good agreement between interfacial shear rheology, emulsion rheology, microstructural parameters and stability. They also confirm the potentials of interfacial shear rheology to predict emulsion microstructure and stability, even before carrying out the emulsification process.

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PO9

Viscosity effects on the morphology development during phase demixing

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So far, the effect of component viscosity (or viscosity ratio) on morphology development has not been systematically investigated in binary liquids. One reason for this lack of knowledge is the difficulty of seeking applicable experimental systems, since liquids of different viscosities often exhibit significant differences in density, polarity, solubility and surface tension. This work presents an attempt to explore the association between component viscosity and the created morphology. By combining silicone oils of different viscosities, we created a series of glycerol/silicon oil systems with various viscosity ratios. We emulsified these systems in the presence of silica nanoparticles and a surfactant, and characterize the formed structures after phase demixing. At a constant shear rate, fluorescent images illustrate different morphologies, including spherical droplets, anisotropic droplets, multiple emulsions and bijel structures, which strongly depend on the viscosity ratio of the system. This dependence is found to be very sensitive; a subtle alteration in the viscosity ratio can cause a rapid phase inversion.

Wednesday 18:10 Foyer Sirene

PO10

Rheology of complex interfaces under extreme deformation

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The rheological behaviour of complex interfaces has profound influence on various industrial and biomedical applications. Determining dilatational viscoelasticity of interfaces is crucial for the design of drug delivery systems, separation processes as well as in the general understanding of the properties and dynamics of soft matter. Many processes rely on the formation and stability of structured interfaces against large-amplitude deformations, at high strain rates and unsteady flow fields to which they may be subjected to during applications. While there are methods to measure this viscoelasticity for strain rates in the range 10^{-1} s^{-1} to 10^2 s^{-1} , a reliable method for measuring the response of such interfaces at higher strain rates is lacking. We propose an oscillating bubble, driven by ultrasound, as an interfacial rheological probe. A bubble driven into small amplitude oscillations remains spherical and therefore exhibits pure dilatation at the interface. This system allows us to study dilatational behaviour at the high deformation rates characteristic of ultrasonic driving in the range 10^3 s^{-1} to 10^6 s^{-1} . As a model system, a colloid-coated Pickering bubble is subjected to low amplitude oscillations and high-speed imaging at 300,000 frames per second is used to extract the resulting radial dynamics. The interfacial stress can be extracted from fitting the radial dynamics to a modified Rayleigh-Plesset equation. In addition, by tracking trajectories of the colloids on the surface of the bubble, we can link the evolution of the microstructure to the measured interfacial stress. This method can be extended to investigate the ultrafast deformations of complex interfaces made of other surface-active agents such as surfactants, polymers, and proteins.

Wednesday 18:10 Foyer Sirene

PO11

The investigation of polyolefin elastomer (POE) foam developments with two blowing agent types by rheological analysisHyo Jae Kong, Seung Hak Lee, and Kyu Hyun[†]*School of Chemical and Biomolecular Engineering, Pusan National University, Busan, Republic of Korea*

To make high performance footwear, better comfortability, stability, lightweight, and impact absorption effect are needed. One of means to enhance such functions is a method that uses a foaming sole by adding a blowing agent to the POE (polyolefin elastomer) matrix. Foaming sole has been produced by injection or expansion foaming process with TPE matrix including curing and blowing agents. These methods, however, have critical problems, such as low production efficiency and dimensional stability. Moreover, it is difficult to expect how much the compound contracts or expands after being removed from the mold. To supplement these defects, a molding-in foaming (MIF) process has been introduced. Because the curing and foaming processes are completed in the mold, final products have the same dimension with mold. Accordingly, it does not require post-processing and can improve production efficiency and dimensional stability. To understand the curing and foaming process during the MIF process, in this study, the effects of curing and foaming processes were investigated with rheological properties and morphologies of POE matrix containing curing agent (dicumyl peroxide, DCP) and two types of blowing agents, i.e., chemical and physical blowing agents, at different concentrations. The curing temperature was determined by degrees of DCP conversion and modulus growth from the temperature ramp tests. As curing process is progressed by thermal decomposition of radical initiator (DCP) above 130 °C, the modulus increases. Axial force as a function of temperature reflected an expansion behavior of the two blowing agent systems (chemical and capsulated blowing agents). In case of chemical blowing agent system (JTR series), axial force came back to its initial level at the end of the test. On the other hand, axial force of physical blowing agent system (FN series) increased continuously to the positive direction during whole process. This different behavior is closely related with the morphology development.

Wednesday 18:10 Foyer Sirene

PO12

Soap films of yield stress fluidsJustin Péméja, Clément Athias, Anne-Laure Biance, Catherine Barentin, and Marie Le Merrer*Institut Lumiere Matiere, CNRS, Univ. Lyon 1, Villeurbanne 69622, France*

Foams are assemblies of soap films used in numerous applications -food industry, elaboration of building materials, depollution- where they are sought for their lightness, their insulating power or their high specific area. In many processes, the liquid phase is in fact a complex fluid, but the role of the complex rheology on foaming properties remains poorly understood. We focus here on the formation of a single soap film, the 'elementary brick' of foams. A film is created by withdrawing a square frame from a liquid bath with a constant velocity. As complex fluids, we use some Carbopol microgels, which behave as yield stress fluids. We characterise the thickness of the entrained film, through absorption or reflectometry measurements, as a function of both the withdrawing velocity and the Carbopol rheological properties. In particular, we will discuss the interplay between the fluid microstructure, made of micron-size polymer blobs, and the film thickness, also in the micron range.

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PO13

Displacement of foamed cement in primary cementingNikoo Hanachi, Amir Maleki, and Ian A. Frigaard[†]*Mechanical Engineering, University of British Columbia, Vancouver, Canada*

The idea of using foamed cement (bubbly liquid cement slurry) in the procedure of primary cementing of wells is to have control over the density. However, some complications arise from the liquid-gas (compressible) mixture. (i) There is an ongoing concern about the stability of the foamed slurry, e.g. as was queried in the enquiry into the 2010 BP Macondo incident [1]. (ii) There are questions regarding how the rheology of the foamed slurry should be modeled. (iii) The stability of the placement flow itself, i.e. assuming that the foamed slurry itself remains intact. We have developed models of primary cementing that include foamed cements. A 1D hydraulic flow model is derived for displacement of foam flow inside the casing. In the annular region outside the casing, we modify the model [2], which was developed to model displacement flows of incompressible fluid, via a 2D gap-averaged model. The main differences of our model compared to an incompressible fluid displacement are: (i) flow in our case is represented with a mass-flux stream function. (ii) density and rheological properties of foam are pressure dependent. For the rheology we use the closure models of [3] for bubbly Herschel-Bulkley fluids, which depend on the volume fraction of gas. Numerical simulation of displacement flows using the resulting model show that the annular flow exhibits buoyancy driven instabilities as the foam advances up the annulus. Such effects have not been reported before in the literature and present worrying implications for the industrial process.

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Wednesday 18:10 Foyer Sirene

PO14

Rheological and curing characteristics of UV-curable PDMS/PEGDMA-Epoxy FilmsNa Hee Kim, Soomin Yoon, Kevin I. Jung, Joon Bang, Anzar Khan, and Hyun Wook Jung*Department of Chemical and Biological Engineering, Korea University, Seoul, Republic of Korea*

Marine organisms can be attached to the vessel surface in marine environments. The marine coatings of underwater vessel part require anti-fouling feature to control and remove bio-fouling. Hydrophilic poly(ethylene glycol)(PEG)-based polymers are used as anti-fouling coating materials because of their low surface energy. Polydimethylsiloxane(PDMS)-based polymers are also utilized as anti-fouling coating materials by reducing adhesion of biofouling. In this study, we investigated rheological and mechanical properties of PDMS-epoxy and PEGDMA-epoxy thick films with anti-fouling capability. Two cross-linkers of methacryloxypropyl terminated polydimethylsiloxane (PDMS) and poly(ethylene glycol) dimethacrylate (PEGDMA) and one monomer of glycidyl

methacrylate (epoxy) were used in the UV curing process. Cured thick films were analyzed by rotational rheometer for rheological properties and nano-indentation / nano-scratch tests for mechanical properties. Considering the amphiphilic coating capability of glycidyl methacrylate with epoxy group that can inhibit attachment of marine organisms, the amphiphilic surface of cured coating films was tuned by generating the hydrophilic and the hydrophobic brush to epoxy group. To evaluate amphiphilic coating, the surface properties of PDMS-epoxy and PEGDMA-epoxy films through water contact angle and x-ray photoelectron spectroscopy(XPS) were scrutinized.

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PO15

Viscoelastic properties of Tri-modal PE Blends

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Ultrahigh molecular weight polyethylene (UHMWPE) gets more and more attention. Using as additive, improves significantly the material properties of the polymer matrix. Polyethylene reactor blends obtained by in-situ blending of ultrahigh- and low molecular weight PE and later mixed with a PE matrix exhibit superior mechanical properties due to the self-reinforcement. Reactor blends (RBy, where y represents the weight percentage of the UHMW part and the rest is shorter chain) consisting of UHMWPE and shorter chains [1] were synthesized and melt-blended with a commercial high density PE (HDPE) in order to obtain tri-modal PE blends. High polydispersity (PDI) and UHMW chains are significantly influencing the rheological behaviour of PE blends [2-4]. Therefore, rheological measurements were performed to study the influence of the very long chains and extraordinary high polydispersity, in range of up to 10^3 , on the molecular dynamics of different tri-modal PE blends (xRBy with x being the weight percentage of RBy). Linear viscoelastic characterization was carried out applying oscillatory shear and creep shear experiments. In order to characterize the non-linear viscoelastic behaviour of the blends, uniaxial extensional measurements were performed. The analysis of data aims at the determination of the influence of UHMW-content on the viscosity, plateau modulus, and terminal relaxation time as well as strain hardening behaviour of these blends.

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Wednesday 18:10 Foyer Sirene

PO16

Self-propelled oil emulsions: an active matter model system

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Self propelled oil droplets in aqueous surfactant solutions offer a rich playground to study active matter phenomena. Driven by self-sustaining interfacial Marangoni stresses, such droplets interact with each other, obstacles and interfaces via hydrodynamic and chemotactic forces. A simple, mass produceable 3-component system in microfluidic geometries already displays intriguing effects like switchable helicity, confinement dependent clustering and chemotactic decision making and dynamical arrest. We present recent findings on this system.

Wednesday 18:10 Foyer Sirene

PO17

Rheological properties of inverse emulsions based on North Sea crude oil

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Inverse water-in-crude oil emulsions are formed in the processes of crude oil production and transportation. The content of water in the emulsions may vary from one oilfield to another depending on productive life of a well. The control of the rheological properties of such emulsions is a tool for creating new technologies of crude oil transportation. In this study, the rheological behavior of North Sea crude oil and water-in-crude oil emulsions was studied by shear rheology method (rheometer Anton Paar MCR 302) in the temperature range from 0 to 30 °C. The emulsion concentration was varied from 1 to 40 vol.%. The influence of temperature, concentration, and dispersion on the emulsion rheology was determined. Crude oil exhibits Newtonian flow behavior even at low shear rates. Viscosity of crude oil increases with the decrease of the temperature. Emulsion viscosity exponentially grows with increasing of the water content, at that the lower the temperature, the stronger this dependence appears. The flow behavior of emulsions with concentrations of 10-40 vol.% is significantly different from crude oil. The non-Newtonian behavior appears at the range of shear rates from 0.001 to 1 1/s, after that the viscosity becomes constant. The relative viscosity increases with increasing emulsion concentration. Virial coefficients in the power function representing the temperature dependence of viscosity were determined. A narrow region of linear viscoelasticity exists on the amplitude dependences of the viscoelastic modules of water-in-crude oil emulsions. In this case, the loss modulus substantially exceeds the storage modulus even for temperatures close to 0 °C. The results can be used to predict the behavior of real crude oil systems during crude oil transportation and for creating new resource-saving and environmentally friendly technologies.

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Wednesday 18:10 Foyer Sirene

PO18

Holographic phase imaging for thickness mapping of thin liquid filmsBiagio Mandracchia¹, Zhe Wang¹, Vincenzo Ferraro², Ernesto Di Maio², Pier Luca Maffettone², and Pietro Ferraro¹¹*Istituto di Scienze Applicate e Sistemi Intelligenti, National Research Council, Pozzuoli, Na, Italy;* ²*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

The dynamics and stability of thin liquid films have fascinated scientists over many decades. Thin film flows occur over a wide range of length, velocity, and liquid properties scales, and are central to numerous areas of engineering, geophysics, and biophysics, attracting considerable attention in the literature, which have resulted in many significant developments in experimental, analytical, and numerical research in this area. We herein introduce the holographic phase imaging microscopy in transmission configuration to measure the full-field thickness map of a liquid film during the dynamic process of bubble formation. The results, gathered on a model aqueous polymeric solution, proved digital holography as an effective and thorough tool for the study of the dynamics of evolving liquid films. Fast acquisition coupled with full-field features of the proposed technique represent a unique tool to access film evolution dynamics, including complex dynamics featuring the formation of chaotic as well as periodic structures.

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PO19

3D-maps on the mechanical behaviour of corkSTFμfluidics composites

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The use of shear thickening fluids for improving the passive damping performance of different materials or systems has skyrocketed in the last decade[1]. Among them, CorkSTFμfluidic composites[2] consists of adding a shear thickening fluid to a cork pad through microfluidic patterns. This approach aims maximizing the damping performance by means of a two-fold major advantage: first, microfluidic channels allows an enhanced shear-thickening behaviour due to its confinement [3]; second, the shape of the microfluidic pattern is susceptible of being optimized numerically [4]. The number of variables of design for the corkSTFμfluidic composites is quite large. In this study, we created a 3D-map in order to help on the assessment of their relative relevance on the mechanical properties of the composites. Thus, 16 sets of CorkSTFμfluidic composites were designed, consisting of 4 different configurations of microchannels (straight, splines, grid and honeycomb) and 4 different fluids (Newtonian, Floc, HydroC, Jam), considering the three different mechanisms responsible for shear thickening behaviour, i.e. shear-induced formation of particle clusters flocculated by polymer bridging, hydrocluster formation, and jamming [5]. 4 low-velocity impact tests (2.5, 5, 10 and 20 J) were performed and the results have been plotted in 3D-maps, which will be of help for establishing a selection protocol of the right shear thickening mechanism in combination of the microfluidic pattern and the impact load providing the optimal performance.

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Wednesday 18:10 Foyer Sirene

PO20

Viscosity of dilute rod suspensions in a Carreau matrix fluidJan Domurath¹, Marina Saphiannikova¹, Gilles Ausias², Julien Férec², and Gert Heinrich¹¹*Institute Theory of Polymers, Leibniz-Institut für Polymerforschung Dresden e.V., Dresden 01069, Germany;*²*Université Bretagne Sud, Lorient, France*

The addition of rod-like filler particles to a liquid leads to a noticeable increase in the viscosity of the mixture. The effect can be described by the Dinh and Armstrong model [1]. One important result of this model is the prediction of a strong increase in the viscosity of the suspension with increasing aspect ratio of the rigid rods. Despite the fact that this model was originally proposed for a Newtonian matrix fluid it is also applied to polymer melts filled with rod-like particles. Such an approach completely decouples the influence of the rod aspect ratio from the non-linear properties of the suspending fluid. Yet, since polymer melts often exhibit strong non-Newtonian behaviour, e.g. shear thinning, it is to be expected that such a superposition will give a wrong prediction of the suspension viscosity. To investigate this problem we performed a numerical study of a suspension consisting of a non-Newtonian matrix fluid and rigid rods. In particular, we simulated different flows of a Carreau fluid around rigid rods with different orientations and used numerical homogenization to obtain the intrinsic viscosity of the suspension as function of applied rate of deformation, thinning exponent and aspect ratio of the rod. In the power law regime of the Carreau model we compared our numerical results with analytical models of Soulloumiac and Vincent [2] and Gibson and Toll [3].

[1] Dinh, S. M. & Armstrong, R. C. (1984). *Journal of Rheology*, 28(3), 207-227. [2] Soulloumiac, B. & Vincent, M. (1998). *Rheologica acta*, 37(3), 289-298. [3] Gibson, A. G. & Toll, S. (1999). *Journal of non-newtonian fluid mechanics*, 82(1), 1-24.

Wednesday 18:10 Foyer Sirene

PO21

Alcohol induced gelation of TEMPO-oxidized cellulose nanofibrils

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Cellulose nanofibrils (CNFs) are colloidal sized fibrils obtained mostly from plant based materials. CNFs present a versatile material from which dispersions or films may be formed [1]. The surface of fibrils may be chemically modified to modulate properties. TEMPO mediated oxidation produces negatively charged fibrils [2]. Oxidized CNFs (OCNFs) can be easily dispersed in water, and caused to gel by of addition of co-solutes; including surfactants, salts, or co-solvents [3,4]. OCNF alcohol/water dispersions form

shear thinning fluids with low yield stress (weak physical gels). These dispersions are quick drying and film forming suggesting that, with adequate rheological profiles, these would allow for a system that can be a physical gel at rest, a shear-thinning sprayable fluid and a quick drying filming forming mixture. In this work, we focus on CNF gelation induced by addition of low M_w alcohol co-solvents. Rheological data showed that all the alcohols studied are capable of inducing OCNF gelation. The addition of alcohol leads to an increase of viscosity, producing shear-thinning fluids, up to a certain critical alcohol concentration at which the gel forms. This critical concentration, and the shear modulus of the gel, depends on the type of alcohol: the more hydrophobic alcohols lead to onset of gelation at lower concentration but exhibiting lower shear modulus. Small-angle X-ray scattering (SAXS) shows that the OCNF behave as rigid rods and, upon gelation, an increase of OCNF cross-section is observed, signalling aggregation. The random phase approximation model [5] was used to extract an interaction parameter that suggests an increase in attractive interactions between OCNFs in presence of alcohols.

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Wednesday 18:10 Foyer Sirene

PO22

Ageing and rheology of TEMPO-oxidized cellulose nanofibril gels

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Nanocellulose is a renewable, biocompatible and biodegradable material with excellent mechanical properties and hygroscopic character. Two main types of cellulose nanoparticles are nanocrystals (nanocrystalline cellulose, CNC) and nanofibrils (nanofibrillated cellulose, CNF). Aqueous suspensions of CNF show stable gel properties at low solids content, due to the hygroscopic character as well as the high aspect ratio and specific surface area of nanofibrils. CNF is commonly obtained by mechanical disintegration of wood in aqueous medium. To enhance the specific surface area of nanofibrils and to prevent their agglomeration different chemical pretreatment methods, such as carboxylation, have been developed. TEMPO (2,2,6,6-tetramethylpiperidine-1-oxyl) mediated oxidation pretreatment, which converts the primary alcohol groups of the cellulose D-glucose units into carboxylate groups, provides the necessary electrostatic repulsion between fibrils. Recently, TEMPO-CNF gels have been studied and designed to meet requirements for applications such as drug delivery, wound covering, tissue engineering, cell encapsulation, aerogels, rheology modifier, nanofiber-reinforced composites. The present study concerns the development of rheological properties of TEMPO-CNF hydrogels prepared from a commercially available TEMPO-CNF powder. Ageing of hydrogels with concentrations from 1 to 3 wt % of TEMPO-CNF was investigated by monitoring shear flow and linear viscoelastic properties after different days from sample preparation. For quantitative representation of the results time dependencies of zero shear viscosity, yield stress and storage modulus are given. By superposition of individual data sets master curves displaying normalized values of the most significant rheological parameters are constructed, showing the effect of concentration on ageing kinetics. Constant parameters' values are reached in about 90 days of storage. The zero shear viscosity and storage modulus values increase for 2 and 1 decade, respectively.

Wednesday 18:10 Foyer Sirene

PO23

Better dopes for fibre spinning from biobased colloids

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Improving the quality and versatility of biobased fibres is essential to enable the transition from oil dependence towards circular economy. Fibres can be produced from biomaterials not only by extraction of native fibres but also by fibre spinning. Herein, the suitability of biobased colloids for fibre spinning was studied by measuring their rheological properties and connecting the results with spinning trials. Dispersions of nanocellulose and its blends and derivatives were considered as examples of spinning dopes because of the abundance of cellulose combined with its light weight and strength. The rheology of the selected dopes was studied under both shear and extensional flows. Furthermore, polarized light imaging was used to examine the structural effects in the system under flow.

Wednesday 18:10 Foyer Sirene

PO24

Reinforcement of suspended spheres on the rheological properties of a molten polymer

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Solid particles suspended in fluids have been extensively studied in the last decades due to the importance in several industrial applications. Shape, size, chemical nature and volume fraction of the suspended particles as well as their dispersion in the matrix are fundamental for the properties of the final product. The current work deals with non colloidal solid spheres of around 15µm in diameter, suspended in a molten polymer, i.e. an entangled polycaprolactone. The volume fraction has been tuned in a way to explore the rheological properties in the dilute and in the concentrated regimes (from 5% to 30% by volume). The suspensions have been prepared via a solvent casting method by using dichloromethane as solvent, which has been, then, properly removed. A good dispersion has been confirmed via electron microscopy. Rheological properties of the suspensions have been carefully studied. In particular, the dependence of the linear viscoelastic moduli on the volume fraction of the suspended particles has been investigated and the results carefully compared to available theories, simulations and experimental data.

Wednesday 18:10 Foyer Sirene

PO25

Structural and transport properties of hard ellipsoidal colloids modeled by event-driven Brownian dynamicsAleena Maria Laganapan and Matthias Fuchs*Department of Physics, University of Konstanz, Konstanz 78457, Germany*

The theory for hard spheres is well-founded and is extensively used in many-body systems. By comparison, our knowledge of nonspherical particles is very limited. For example, real systems are still generally described with respect to their deviations from the hard-sphere model. Hard ellipsoids serve as natural extensions of the hard-sphere model and they can exhibit a wide range of new properties, such as liquid crystalline order, that one can explore. We study the dynamics of the system of hard ellipsoids using an event-driven Brownian dynamics. The main challenge for the computer simulations of the Brownian motion of hard particles is the sampling of random displacements without overlaps. In this regard, we follow the algorithm proposed by Donev and De Michele [1, 2] where an overlap-potential, that depends on the ellipsoids' relative translation and rotation, is used to calculate the next collision time. The model was tested for aspect ratios between 1.5 to 2.8. To benchmark the model, the mean-squared displacements and mean-squared angular displacements are calculated and compared with experimental systems. By benchmarking the single particle motion, the structural and transport properties can be used to gain insight into dense dispersions of anisotropic colloids.

[1] Donev, A. et al. (2005). *Journal of computational physics*, 202(2), 737-764. [2] De Michele, C. et al. (2007). *Physical review letters*, 98(26), 265702.

Wednesday 18:10 Foyer Sirene

PO26

Drying dynamics of suspension drops containing particles with different shapes using multi-speckle diffusing wave spectroscopyKevin I. Jung¹, Baek Sung Park¹, Won-Gi Ahn¹, Seong Jae Lee², Kwan-Young Lee¹, and Hyun Wook Jung¹¹*Department of chemical and biological engineering, Korea university, Seoul, Republic of Korea;* ²*Department of Polymer engineering, The university of Suwon, Suwon, Republic of Korea*

Suspensions with particles are ubiquitously used in various industrial fields (e.g., electronics, pharmaceuticals, secondary batteries, and fuel/solar cells). During the drying of suspension drops, particles migrate to the edge of drops and finally form a ring-like structure called "coffee-ring effect". This non-uniform particle structure is regarded as a critical defect in particulate coating/drying systems. In this study, "coffee-ring effect" of suspension drops containing different particle shapes (spherical and ellipsoidal particles) was examined in real time, using multi-speckle diffusing wave spectroscopy (MSDWS), which is a light scattering method. β -relaxation of the suspension, representing the fast motion of particles at short lag time, was captured by a line scan camera and analyzed by means of the autocorrelation function. Slow motion of the total particle system (α -relaxation) was elucidated via the inertia moment method using CCD camera. The coffee ring patterns of evaporated suspensions were compared by SEM images and 3D optical profiles. Finally, particle mobility predicted from MSDWS was correlated with the final coffee-ring structure. Drying patterns of drops could be clearly divided into compacting and air-invading stages. Compared to the case with spherical particles, ellipsoidal particles with lower mobility in a suspension drop prolong the period of air-invading stage in drying process due to the loosely-packed pore structures between particles.

Wednesday 18:10 Foyer Sirene

PO27

Study of layer-formation in concentrated suspensions in parallel plate rheometer during steady state and transient developmentYusra Hambal, Steffen Jesinghausen, and Hans-Joachim Schmid*Paderborn University, Paderborn 33098, Germany*

The rheological characteristics of suspensions are significantly influenced by the microstructural changes (particle migration, confinement induced layering) caused by any constraints and therefore in measurement devices as well. Thus, the transferability of rheological measurements of suspensions to real problems is only possible if the structure of the suspensions is known. The phenomena of layering was reported long ago, but has not been understood completely up to nowadays. In recent years, with new given analysis techniques the research has been intensified. However, most times such layering effects have been studied using concentric cylinder setups [1] as Plate-Plate setups are confronted with problems concerning the accessibility, especially for optical techniques. Parallel plate setups with guard rings solve these problems but have their own limitations [2]. Measuring the layering effects by means of computer tomography need a very complex setup, is very expensive and limited in the transient case [3]. We present a new kind of setup that combines the advantage of optical accessibility without guard rings and a simple and fast imaging technique. The arrangement of the setup offers the possibility of observing the steady and the transient state as well. The presented work aims for the investigation of the layer-formation and its structure in highly concentrated PMMA. In this regard, different parameters are studied, such as different gap heights, particle size to gap height ratio and polydispersity of the particles.

[1] Blanc, F. et al. (2011). *Journal of Rheology*, 55(4), 835-854. [2] Pieper, S. & Schmid, H. J. (2016). *Journal of Non-Newtonian Fluid Mechanics*, 234, 1-7. [3] Deboeuf, S. t al. (2018). *Journal of Rheology*, 62(2), 643-663.

Wednesday 18:10 Foyer Sirene

PO28

Creep response of a soft glassRaffaella Cabriolu¹, Pinaki Chaudhuri², and Kirsten Martens³¹*Department of Chemistry, Norwegian University of Science and Technology, Trondheim 7032, Norway;* ²*Institute of Mathematical Science, Chennai, Tamil Nadu 600113, India;* ³*Laboratoire Interdisciplinaire de Physique UMR 5588, Centre National de la Recherche Scientifique, Saint Martin d'Hères, France*

In this work we discuss finite size effects in the fluidization process of dense amorphous materials subjected to an external load. By means of molecular dynamics simulations we study the mechanical response of a densely packed 3D particle system to a sudden applied shear stress. In order to disentangle possible boundary effects from finite size effects, we use an unusual setup by implementing a geometry-constraint protocol with periodic boundary conditions in all directions. We show that this protocol is well controlled and that the long time fluidization process is to a great extent independent of the details of the protocol parameters. This procedure allows for a robust study of finite size effects regarding the creep exponents and the fluidization process.

Wednesday 18:10 Foyer Sirene

PO29

Numerical investigation of colloidal gels under shearJose Ruiz-Franco¹, N. Gnan², and E. Zaccarelli²¹*Department of Physics, Università La Sapienza di Roma, Rome, Lazio 00185, Italy;* ²*CNR Institute of Complex Systems, Uos Sapienza, Rome, Lazio 00185, Italy*

Soft matter systems have the intriguing property to be able to form a variety of different arrested states, encompassing (among others) repulsive, attractive glass and gels. In this work, we study numerically a gel-forming colloidal system, modeled by a combined Lennard-Jones and Yukawa potentials, under the effect of shear. In particular, we assess the physical implications of using two different Molecular Dynamics approaches: the first one is based on SLLOD equations coupled with a Gaussian thermostat (MD-GAUSSIAN), whereas the second one uses a Langevin thermostat (MD-LANGEVIN). By applying the former protocol under high shear rates, the network formed at percolation is broken into small clusters; lower shear rates cause the gel system to rearrange into a more stable state, i.e. a crystal. In case the shear flow is introduced in the system via an implicit solvent, thus by employing the latter approach, the crystallization process starts at longer times and we notice an increased relevance of the repulsive potential tail. After providing proofs of the above-mentioned behaviors, we aim to establish a mapping among the two MD approaches as to determine the range of shear flow in which both descriptions are comparable.

Wednesday 18:10 Foyer Sirene

PO30

Rheo-optics and the nonlinear material behavior of cellulose noncrystals suspensionsRoland Kádár¹ and Tiina Nypelö²¹*Industrial and Materials Science, Chalmers University of Technology, Gothenburg SE-412 58, Sweden;* ²*Chemistry and Chemical Engineering, Chalmers University of Technology, Gothenburg SE-412 58, Sweden*

The shear rheology of aqueous cellulose nanocrystals (CNC) suspensions is explored in this study. The tests were performed on an Anton Paar MCR702 TwinDrive rheometer in stress-controlled mode / single-motor transducer, in strain controlled mode / separate motor-transducer and counter-oscillation. A custom setup was used for simultaneous steady and oscillatory shear tests and polarized light imaging in stress controlled mode. The morphological changes as a result of the flow field CNC interaction were observed using space-time imaging. The coupled polarized light imaging was able to reveal the nematic ordering of the CNCs at different stages of shearing. Complementary tests were performed in strain-controlled mode, including nonlinear oscillatory shear analysis. The nonlinear analysis of the shear stress output signal was performed in the framework of Fourier-Transform analysis and Tchebyshev polynomial decomposition. Preliminary results highlight the importance of the shear history on the nonlinear materials response and the underlying structure, as observed through polarized light imaging. The results point to that shear and shearing conditions are crucial for controlling CNC alignment. The ultimate goal of the study is to aid in the design of processing techniques for CNC-based composites.

Wednesday 18:10 Foyer Sirene

PO31

Boycott effect in horizontal annular geometriesAgathe Robisson*Civil Engineering, TU Wien, Vienna, Austria*

We evaluate the settling of a suspension in an annular geometry, where the concentric pipes are placed horizontally. The geometry was chosen to mimic cement bleeding (accumulation of fluid on top of the geometry due to the settling of particles) in horizontal oil and gas wells. We compare the behavior of ideal semi-dilute suspensions (polymer particles in oil) with real cement slurries in cells of same geometry. Our results show striking similarities between the slurry and the ideal suspension, and explain the presence of weak points at the upper outer diameter, below the internal diameter and at the poles. This work aims at predicting defects in cement placed in horizontal oil and gas wells in tight reservoirs, where hydraulic fracturing treatments are crucial. Such defects may compromise the hydraulic isolation in the well, affecting the fracturing treatment, and eventually leading to a lower hydrocarbon production.

Wednesday 18:10 Foyer Sirene

PO32

Rheology and electrorheology of suspensions of elongated iron oxyhydroxide particles in silicone oilSaket Kumar and Prachi Thareja*Chemical Engineering, Indian Institute of Technology Gandhinagar, Gandhinagar, Gujarat 382355, India*

We investigate the rheology and structure of the suspensions of elongated iron oxyhydroxide (FeOOH) particles (length = 500 nm, aspect ratio = 5) in silicone oil as a function of particle volume fraction (Φ) and an external electric field (E). In the absence of an external electric field, the suspensions undergo transition from liquid-like to solid-like behaviour at a FeOOH particle Φ of 0.054, which is rheologically concomitant with an abrupt rise in storage modulus (G') of the order of 10^3 Pa and $G' > G''$ (loss modulus) in the experimental range of angular frequency (ω). The suspensions with FeOOH particle Φ of 0.025 and 0.039 exhibit viscosity build-up over time during a step-down from 10 s^{-1} to lower shear rates, indicative of the existence of the thixotropic behaviour. Moreover, on the application of an external $E = 0.5 \text{ kV/mm}$, the liquid-like to solid-like transition occurs at a comparatively low FeOOH particle Φ of 0.025, which is attributed to the E driven network formation of elongated FeOOH particles in the silicone oil medium. The microscopy images of suspensions with FeOOH particle Φ of 0.025 reveals that in absence of E, the particle aggregates remain randomly distributed however, once $E = 0.5 \text{ kV/mm}$ is applied, the particles form a system spanning 3-D network in the direction of applied E. We further show that the yield stress (τ_y) does not follow the conventional quadratic dependence on the applied E, rather it scales $\tau_y \sim E^{1.5-1.6}$, which suggests the dominance of conduction forces over polarization forces.

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PO33

Non-isothermal elongational flow of polymer nanocompositesFrancesco Paolo La Mantia, Maria Chiara Mistretta, Manuela Ceraulo, and Luigi Botta*Dip. di Ing. Civile, Ambientale, Aerospaziale, dei Materiali, University of Palermo, Palermo, Italy*

The elongational flow is a very important flow involved in important processing operations, like spinning, film blowing, etc. In these processing operations, the molten polymer is subject to the elongational flow and at the same time is cooled (non-isothermal elongational flow). The response to the non-isothermal elongational flow of the melt is then the critical parameter to process the polymer in these processing operations. MS (melt strength) and BSR (breaking stretching ratio) are two values measured during the non-isothermal flow and depend mainly on the molecular structure of the polymer. In biphasic systems, the adhesion and the shape of the dispersed particles play a very important role in determining the behaviour of the melt under this flow. Polymer nanocomposites are biphasic systems where the rigid dispersed particles are of nanometric size and this size and the adhesion with the matrix are of relevant importance when these systems are subjected to the non-isothermal elongational flow. In this communication, the non-isothermal elongational flow behaviour of some polymer nanocomposites systems is reported and the effects of the elongational flow on the morphology of polymer nanocomposites are described. The change of the morphology of some of these systems (organoclay modified and graphene nanocomposites) subjected to elongational flow is somehow similar to that already reported for polymer blends. In particular, reduction of the dimensions, exfoliation and alignment along the flow direction have been observed.

Wednesday 18:10 Foyer Sirene

PO34

Controlling the whiskers selective location and the rheology in HDPE/PA6 immiscible blends to improving thermal conductivityAna Ares-Pernas¹, Xoan García¹, Carmen Cerecedo², Victor Valcárcel², and María José Abad-López¹¹*Grupo de Polímeros, Universidade da Coruña, Ferrol 15471, Spain;* ²*Neoker, S.L, O Milladoiro 15895, Spain*

High thermal conductivity and high electrical resistivity are desired in different applications as protective housings for electronic devices. In the literature there are several attempts to achieve this goal, introducing fillers with high thermal conductivity, using hybrid thermal conductive fillers to reduce the filler content, etc... Moreover, in the most recent studies is pointed out that this outcome can be achieved by controlling the selectively location of fillers in a phase of a immiscible polymer blend. In these work, alumina whiskers composites (insulating filler) were melt-mixing by extrusion in different ratios of HDPE/PA6 immiscible blends. The global aim is optimize the thermal conductivity of composites using the minor amount of filler in an immiscible polymer blend. For this purpose, the more suitable morphology, which favors the formation of thermal conductive paths, will be searched. With this aim, the mixing strategy, the ratio of HDPE/PA6 and the filler amount were well-designed to control the rheology properties which affect the composites morphology and, consequently, the macroscopically properties. The rheology characterization of designed composites was performed by small amplitude oscillatory shear experiments. Additionally, other strategies were followed too: on the one hand, coalescence experiments were performed using different shear rates to induce this phenomenon. On the other hand, selected nanofillers were additionally introduced in the composite. In all cases, relationships among rheology, morphology and properties were established. In each case, electronic microscopy was used to determine the composite morphology and the laser flash technique to measure the thermal diffusivity and thermal conductivity of composites.

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PO35

Innovative additive-free silver paste formulation for high performance solar cellsCeren Yüce and Norbert Willenbacher*Institute for Mechanical Process Engineering and Mechanics, Karlsruhe Institute of Technology, Karlsruhe 76131, Germany*

Front side metallization of Si-solar cells is usually realized using traditional screen-printing to apply commercial silver pastes including a complex mixture of solvents, binders and surfactants besides the particles. We present an innovative paste formulation concept enabling high quality screen printed front side metallization of Si-solar cells. This new formulation strategy is based on the

so-called capillary suspension phenomenon. A particle network is formed by capillary bridges formed by a small amount of an immiscible secondary fluid added to a pure suspension consisting of silver particles and a bulk fluid. Generally, storage stability can be guaranteed and flow behavior of such capillary suspension-type pastes can be tuned in a wide range by appropriate choice of the type and amount of secondary fluid. In printed electronics application this is particularly beneficial, since no binders, dispersing agents or rheology control additives are necessary potentially deteriorating the electrical properties in the finally printed and sintered pattern. Yield stress, low shear viscosity and also the wetting behavior of the used solvents can be adjusted to achieve narrow line widths and high aspect ratio. The pastes exhibit a strong degree of shear thinning which allows for conventional screen-printing through narrow mesh openings down to 25 μm . During sintering the bulk and secondary fluid evaporate and our results demonstrate that similar solar cell performances can be reached at a substantially lower silver consumption (silver deposit about 25 % lower than with state-of-the-art commercial pastes). Energy dispersive electron microscopy (EDX) imaging suggests that the higher conductivity of the additive-free formulation is due to a lower carbon content in the sintered lines compared to lines printed from conventional pastes. This findings show that we are on a good way to reach industrially feasible finger widths using the screen printing technique and cell efficiencies beyond the current state-of-the-art.

Wednesday 18:10 Foyer Sirene

PO36

Strain-Temperature-Transformation diagram for colloidal suspensions by dynamic mechanical measurements

Bin Xia and Xiaorong Wang

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Recent advances in synthesis of soft particles, such as star polymers and hairy particles, have provided the ability to control the flow state of colloidal suspensions by changing particle microstructure and interactions, and meanwhile have put colloidal suspension rheology at the forefront of soft matter research. The gelled colloidal suspensions can be easily transformed from the solid-like state to a liquid-like state by heating or shearing. Here, we report a non-monotonic strain-temperature phase diagram, a surprising Z-shaped curve, of the solid-liquid transition of colloidal suspensions by oscillatory shear measurements. This discovery not only broadens our understanding of the complexity of suspensions, but also provides an opportunity to make an intensive study of the relationship between microstructure and macroscopic properties of colloidal suspensions.

Wednesday 18:10 Foyer Sirene

PO37

Mullins' effect in rubbers filled with core-shell nanoparticles of tapered interface structure

Lin Wang¹ and Xiaorong Wang²

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The factors responsible for Mullins' effect in filler-reinforced rubbers have been studied for many years. In this work, core-shell nanoparticles of tapered interface structures were synthesized. The hard core is made from crosslinked polystyrene, and the soft hairy shell is made of tapered poly(isoprene-co-styrene). We found that these core-shell nanoparticles can provide superior reinforcement in rubber compounds. Rubbers filled with these particles exhibit varied stress-softening behavior, which depends on the filler internal structures. We discussed how this variation is reflected in tensile strength and wear resistance.

Wednesday 18:10 Foyer Sirene

PO38

Soft colloidal mixtures in temperature dependent solvents

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Mixtures of soft colloids of varying softness and size ratios are known to exhibit a very rich rheological state behavior, characterized by the wide-ranging interactions and the osmotic compression of the particles [1]. Taking the particular example of star polymers, a paradigm of hairy particles, it has been reported that their mixtures with size ratio around 0.7 in athermal solvent, at high concentrations with both stars dynamically frozen, exhibit a double glass to liquid to asymmetric star transition upon increasing fraction of small stars [2]. Given that stars can swell upon heating when dispersed in solvents of intermediate quality, hence enhance their effective volume fraction, yielding a liquid-to-glass transition [3], an interesting question is how the rheology of the mixtures will be influenced by the temperature. In addition to the scientific challenge, as we introduce enthalpic interactions to a system with excluded volume and osmotic interactions, this has implications in applications as it provides an additional means to tailor the flow properties of colloidal composites. We address this challenge and present here preliminary results on the rheology and dynamics of 1,4-polybutadiene star mixtures of varying functionality and arm molar mass, with size ratio of 0.7, dispersed in n-tetradecane. We focus on the linear viscoelastic response, determine the temperature-dependent effective volume fraction and discuss its effect on plateau modulus and relaxation time of individual stars and their mixtures at different compositions. More importantly, the small stars act as inhibitors to vitification of the larger ones at all temperatures. This system is proposed as a model to investigate the rheology of this yet-unexplored regime combining softness, entropic and enthalpic interactions.

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Wednesday 18:10 Foyer Sirene

PO39

The influence of solid phase particles content on the stability, rheological and force absorbing properties of shear thickening fluids

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Shear thickening fluids are smart materials which provide lots of opportunities for creating a composites with great energy absorption ability. This structure could be used in a variety of applications; for example in smart armours or sport protectors. Good dilatant fluids have to have not only appropriate rheological properties and protecting capability, but also they cannot change the properties over time. In the current experiment two types of shear thickening fluids were used. To produce STF's 50 and 55% volume fraction of amorphous silica were mixed with polypropylene glycol of 2000 molar mass. The stability were measured using the device for characterizing concentrated liquid dispersions - Turbiscan LAB Formulation. Rheological studies were performed using an ARES rheometer, equipped with two parallel plates with a gap between them of 0.3 mm. All the viscosity measurements were taken at the room temperature. Subsequently the STF's were placed in silicon forms for force absorbing tests, which were performed by dropping an impactor with the energy of 5 J.

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PO40

Microstructural changes in colloidal rod glasses undergoing shear flow – Investigation by rheology and confocal microscopy

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Anisotropic rod like colloidal particles can form liquid - crystalline phases (LC) unlike spherical particles. Formation of such phases is controlled by particle concentration, external stimuli (thermal, electrical, magnetic or flow) or by tuning the inherent properties of the particles (electrostatic or steric stabilization). Predicting microstructural changes in rod like colloidal suspensions undergoing shear flow is complicated due to the changes in particle orientational and positional distribution. These changes can lead to phase transition from isotropic to nematic or smectic. Furthermore, this transition is influenced by particle size, aspect ratio, surface properties, polydispersity, flexibility, shear rate, etc. This means additional probing techniques such as scattering or optics are needed in conjunction with rheology to clearly explain the rod like colloidal behavior under flow. Microscopic silica rods have been shown to form additional LC phases when compared to ellipsoids and are a model system to study ideal hard rods of low aspect ratio (~5-10). We present here a study of the changes in microstructure of glasses of silica rod particles at different particle volume fractions undergoing shear flow. Micron sized silica rods ($L = 5 \mu\text{m}$, $L/D = 10$) coated with fluorescence dye are suspended in refractive index matched medium (85 wt% glycerol water mixture). The changes in particle microstructure in the suspension during shear flow are captured by combining rheology with confocal microscopy. This technique allows us to track individual particle trajectory in the concentrated regime in the linear and nonlinear rheological measurements. Furthermore, we tune the interparticle interaction from repulsive to attractive with the addition of a suitable salt. These measurements further allow us to propose a phase diagram in the repulsive and attractive regime.

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PO41

Linear viscoelastic behavior of PMMA/grafted PBA melts

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The viscoelastic properties of poly(methyl methacrylate) (PMMA)/grafted poly(butyl acrylate) (PBA) nanoparticle systems were investigated. The rubber particles consist of PBA core and grafted PMMA shell. The availability of time-temperature superposition depended on the composition of PBA particles. This results from the particle-particle interaction of grafted PBA particles, though the samples obeyed TTS at high τ associated with the relaxation with entanglement of matrix PMMA.

Wednesday 18:10 Foyer Sirene

PO42

Effects of polydispersity on the glass transition dynamics of aqueous suspensions of soft spherical colloidal particles

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Thermoresponsive poly(N-isopropylacrylamide) (PNIPAM) particles of a nearly constant swelling ratio and with polydispersity indices (PDIs) varying over a wide range (7.4% - 48.1%) are synthesized to study the effects of polydispersity on the dynamics of suspensions of soft PNIPAM colloidal particles. The PNIPAM particles are characterized using dynamic light scattering (DLS) and scanning electron microscopy (SEM). The zero shear viscosity (η_0) data of these colloidal suspensions, estimated from rheometric experiments as a function of the effective volume fraction (Φ_{eff}) of the suspensions, increases with increase in Φ_{eff} and shows a dramatic increase at $\Phi_{\text{eff}} = \Phi_0$. The data for Φ_0 as a function of Φ_{eff} fits well to the Vogel-Fulcher-Tammann (VFT) equation. It is observed that increasing PDIs results in increasingly fragile supercooled liquid-like behavior, with the parameter Φ_0 , extracted from the fits to the VFT equation, shifting towards higher Φ_{eff} . The observed increase in fragility is attributed to the prevalence of dynamical heterogeneities (DHs) in these polydisperse suspensions, while the simultaneous shift in Φ_0 is ascribed to the decoupling of the dynamics of the smallest and largest particles. Finally, it is observed that the intrinsic nonlinearity of these suspensions, estimated at the third harmonic near Φ_0 in Fourier transform oscillatory rheological experiments, increases with increase in PDIs. Our results are in agreement with theoretical predictions and simulation results for polydisperse hard sphere colloidal glasses and clearly demonstrate that jammed suspensions of polydisperse colloidal particles can be effectively fluidized with increasing PDIs.

Suspensions of these particles are therefore excellent candidates for detailed experimental studies of the effects of polydispersity on the dynamics of glass formation.

Wednesday 18:10 Foyer Sirene

PO43

On the capillary extensional rheometry of concentrated colloidal hard sphere suspensions

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CaBER-1 is one of the two commercial rheometers currently available in the market able to perform the rheological characterization of mobile liquid under uniaxial extensional flow conditions. It imposes an extensional step strain and the filament thins under the influence of capillary forces, where the extensional strain rate is defined by the extensional properties of the sample. For viscoelastic and Newtonian liquids, it is possible to relate the time evolution of the midpoint diameter of the necking filament with the relaxation time, nevertheless some requirements must be accomplished while setting the experiment conditions in order to rely on the obtained results. As the use of CaBER device with concentrated suspensions is rather scarce in the literature, there is a need for a systematic study in order to determine the conditions under which extensional rheometry can be performed with such samples, i.e. initial and final height, diameter of the plates, velocity profile imposed to separate the plates (linear or exponential), etc. In this study, concentrated colloidal hard sphere suspensions, with different particles sizes, are examined experimentally with the CaBER set-up. Different linear and extensional velocity profiles have been imposed and the time evolution of the filament thinning process have been recorded by means of a high speed camera. The imposed initial strain rate depends directly on the stretching profile and the time to reach the final height (streak time). The results, which have been analyzed in terms of the dimensionless diagram $t_{\text{brake}}/t_{\text{bolzmann}}$ Vs Pe , showed that samples tend to jam at lower Pe with the extensional profile than with the linear one. This fact can be explained in terms of the defined streak time: for the same imposed strain rate, the streak time is shorter for the exponential profile than the linear one. The results highlight the importance of the streak time as key parameter to define the degree of structure developed in the concentrated colloidal hard sphere suspensions.

Wednesday 18:10 Foyer Sirene

PO44

Rheology of patchy emulsions

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Many industrial soft materials often include oil-in-water (O/W) emulsions at the core of their formulations. If the surfactant or particle employed to stabilize the interface is responsive to external stimuli such as temperature, O/W emulsions can be used as reconfigurable fluids [1]. The means to promote their self-assembly in a programmable way is a rapidly developing research topic as it can lead to a new class of dynamically tuneable soft materials. DNA hybridization has already proved to be ideal for the creation of functional and patchy droplets thanks to its thermo-reversibility and high specificity [2]. They uniquely exhibit natural "patchiness" due to the mobility of the linkers on the interface, which in turn allows for programmed sequential self-assembly of the building blocks [3]. Such "patchy emulsions" are thought to offer great potential rheological advantage since precise control of the material microstructure can be achieved: this could revolutionize the field of soft material rheology. However, up until now emulsion droplets functionalized with DNA had relatively low coating densities and were expensive to scale up, limiting their experimental investigation. In this talk we will present a general O/W DNA-coating method using functional non-ionic amphiphilic block copolymers. The hydrophilic polyethylene glycol ends of the surfactants are functionalized with azides, allowing for efficient, dense and controlled coupling of dibenzocyclooctane functionalized DNA to the polymers through a strain-promoted alkyne-azide click reaction. The protocol is readily scalable since it can be coupled to commercially available surfactants. After a brief introduction of our emulsion system, thermoreversible sub-micron gels of patchy emulsions are demonstrated. We illustrate their rheological behavior by means of both bulk rheology and microrheology and showcase their strikingly different microstructure to that of their isotropic counterparts. Our experimental findings are supported by simulation studies. The present work demonstrates that we can achieve control over the rheological properties of patchy emulsions by simple tuning of the system parameters and opens up new applications in soft matter and biotechnological research and industrial advances.

[1] Zarzar, L. D. et al. (2015). *Nature*, 518(7540), 520. [2] Joshi, D. et al. (2016). *Science advances*, 2(8), e1600881. [3] Zhang, Y. et al. (2017). *Nature Communications*, 8(1), 21.

Wednesday 18:10 Foyer Sirene

PO45

Predicting and assessing rupture in protein gels under oscillatory shear

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Physics, Ens de Lyon, Lyon, France

Soft materials may break irreversibly upon applying sufficiently large shear oscillations, a process whose physical mechanism remains largely elusive. In this work, the rupture of protein gels made of sodium caseinate under an oscillatory stress is shown to occur in an abrupt, brittle-like manner. Upon increasing the stress amplitude, the build-up of harmonic modes in the strain response can be rescaled for all gel concentrations. This rescaling yields an empirical criterion to predict the rupture point way before the samples are significantly damaged. "Fatigue" experiments under stress oscillations of constant amplitude can be mapped onto the former results, which indicates that rupture is independent of the temporal pathway in which strain and damage accumulate. Finally, using ultrasonic imaging, we measure the local mechanical properties of the gels before, during and after breakdown, showing that

the strain field remains perfectly homogeneous up to rupture but suddenly gives way to a solid-fluid phase separation upon breakdown.

Wednesday 18:10 Foyer Sirene

PO46

Application of fixed point iteration algorithm to the conversion from the Laplace transform of relaxation modulus to continuous spectrum

Junghaeng Lee and Kwang Soo Cho

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Continuous relaxation spectrum cannot be measured directly but it can be calculated from measurable viscoelastic functions such as dynamic and relaxation modulus. Because of ill-posedness, relaxation spectrum is doubted an ambiguous quantity. However, the uniqueness of relaxation spectrum is proven mathematically although its calculation suffers from ill-posedness. It could be proven mathematically that relaxation spectrum has higher resolution than any other linear viscoelastic function. Hence, it is needed to develop algorithm for relaxation spectrum from various kinds of rheological data. Most algorithms of continuous spectrum consider dynamic modulus as the raw data. It is because dynamic modulus is measured more accurately than relaxation modulus. Another reason of using dynamic modulus could be found from the following equation: $G''(\omega) = \int_{-\infty}^{\infty} H(\lambda) (\omega\lambda) / (1 + \omega^2\lambda^2) d\log\lambda$ (Eq. 1). The kernel of the integral equation has the shape of a peak when it is plotted as a function of $\log(\omega\lambda)$. On the other hand the relation between spectrum and relaxation modulus has different kernel function: $G(t) = \int_{-\infty}^{\infty} H(\lambda) \exp(-t/\lambda) d\log\lambda$ (Eq. 2). The kernel $\exp(-t/\lambda)$ does not have the shape of a peak. Cho and Park developed fixed-point iteration (FPI) which exploits the properties of kernel function mentioned above [1]. Since FPI has a simple mathematical form and is very fast, we develop a method to apply FPI to the data of relaxation modulus. Taking Laplace transform, Eq. (2) becomes: $\sqrt{s}G(s) = \int_{-\infty}^{\infty} \sqrt{\lambda}H(\lambda) \sqrt{s\lambda} / (1 + s\lambda) d\log\lambda$ (Eq. 3). Then the kernel of Eq. (3) is similar to that of Eq. (1).

[1] Soo Cho, K. & Woo Park, G. (2013). Journal of Rheology, 57(2), 647-678.

Wednesday 18:10 Foyer Sirene

PO47

Point-wise method for the direct conversion of creep data to dynamic modulus

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It is interesting to convert the data of Laplace transform of relaxation modulus to those of dynamic modulus without relying on relaxation spectrum because all raw data of linear viscoelastic measurements can be expressed by the relation between the Laplace transforms of input and output functions. When strain is given to a linear viscoelastic material, the stress is related by: $\sigma_L(s) = sG_L(s)\gamma_L(s)$ (Eq. 1), where $\sigma_L(s)$, $\gamma_L(s)$, $G_L(s)$ are, respectively, Laplace transforms of stress, strain and relaxation modulus. It is not difficult to obtain $\sigma_L(s)$ and $\gamma_L(s)$ from the raw data of $\sigma(t)$ and $\gamma(t)$ [1]. Since $G(t)=0$ for $t<0$, we can exploit the similarity between Laplace and Fourier transform: $G_F(\omega) = \int_{-\infty}^{\infty} G(t)e^{-i\omega t} dt = \int_0^{\infty} G(t)e^{-i\omega t} dt = G_L(i\omega)$ (Eq. 2), where $G_L(i\omega) = \int_0^{\infty} G(t)e^{-i\omega t} dt$ (Eq. 3). Furthermore, we know that: $sG_L(s)_{s=i\omega} = G'(\omega) + iG''(\omega)$ (Eq. 4). If we know the mathematical form of $sG_L(s)$, then use of Eq. (4) gives dynamic moduli. Kwon et al. (2016) suggested tool box for the direct conversion using Eq. (4) [1] while their algorithms have merits and demerits. In this presentation, we will show improved algorithms.

[1] Kwon, M. K. et al. (2016). Journal of Rheology, 60(6), 1181-1197.

Wednesday 18:10 Foyer Sirene

PO48

Tridimensional rheological characterization of magneto rheological fluids

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Typically, the standard measurements of Magnetorheological fluids apply vertical magnetic fields versus the applied shear. In the present work, it will performed oscillatory measurement in several directions versus the applied magnetic field. The main target is, from a practical point of view, to establish the relationship between the rheological properties and the magnetic field applied not only in the perpendicular direction but also in the other 2 spatial directions. In order to get that target, an orthogonal superposition geometry has being build made off plastic based in the Standard Double Gap Couette geometry. This geometry allows us to perform several kinds of stresses: s_{12} , s_{32} , s_{23} and therefore, not only G_{12} will be measured but also G_{32} , and G_{23} . A solenoid is built surrounding the Plastic OSP geometry what provides the magnetic field intensity required.

Wednesday 18:10 Foyer Sirene

PO49

A simple non-Newtonian standard fluid for intra laboratory rheometer comparison

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Aim of this study was to evaluate a simple fluid with shear thinning behaviour for validating a newly developed Rheometer for whole blood viscosity measurements in two different laboratories in Austria and Japan [1]. Beside other non-Newtonian standard solutions [2], Xanthan gum (E 415) is an international available low cost and nontoxic food additive. It is an exopolysaccharide produced by bacteria *xanthomonas campestris* NRRL B-1459 [3]. Xanthan gum has a shear thinning behaviour and is used in the food industry for its ability to form viscous solutions at low concentrations and for its stability in a wide pH and temperature range. Solutions of Xanthan gum dissolved in drinking water with concentrations from 0.05%, 0.1%, 0.2%, 0.25%, 0.5% and 1.0% were used to test concentration dependency as well as shear thinning behaviour at 22°C. Solutions were measured with an Anton Paar MCR 301 Rheometer (Anton Paar, Graz, Austria) with a cone-plate system. One concentration was measured with a temperature ramp from 7°C to 42°C in 5°C steps. Results show a non-Newtonian behaviour of the Xanthan solution. Viscosity showed a strong

temperature dependency and shear thinning behaviour and the measurements were highly reproducible. With this solution, it will be possible to validate rheological measurement systems for their accuracy and their suitability in measuring non-Newtonian fluids.

- [1] Suzuki, T. et al. (2012). Applied Physical Sciences, Biophysics and Computational Biology, 109(51), 5. [2] Schultesiz, C. R. & McKenna, G. B. (2000). Technical Papers of the Annual Technical Conference-Society of Plastics Engineers Incorporated. 58(1). [3] Lopes, B. D. M. et al. (2015). Journal of Food and Nutrition Research, 54(3), 185-194.

Wednesday 18:10 Foyer Sirene

PO50

Impact of instrument inertia on oscillatory shear measurements with rotational rheometers

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There are two different operating principles for rotational rheometers. In one design, the torque is measured at the moving surface, i.e. the motor current is taken as a measure of the torque. The working mode of such rheometers is called combined motor transducer (CMT) mode. Historically, such types of rheometers are also known as stress controlled instruments. In a different design, a motor drives one member of the geometry and the torque is measured as the torque, which is needed to keep the second member nearly fixed. This working mode is called separate motor transducer (SMT) mode and historically such types of rheometers are called strain controlled instruments. Because in a CMT mode the torque is measured at the moving surface, the moment of inertia of the moving parts of the instrument might influence the measurement results. Therefore responsible is a large ratio of acceleration to sample torque which is a function of the momentum of inertia of the measuring system, the angular frequency, the modulus of the complex viscosity and the geometry factor (k) of the measuring system. The geometry factor k is inversely proportional to the radius to the third power (cone-and-plate) or fourth power (plate-plate). Hence, increasing the radius of the measuring system can reduce the ratio of acceleration to sample torque and increase the accuracy of the determination of rheological properties. Contrary to this, in SMT mode instrument inertia effects can be neglected. In order to investigate inertia effects oscillatory shear measurements have been performed with different measuring geometries using a MCR 702 rheometer suitable to work in CMT and SMT mode. For a CMT situation, it is shown that with an appropriate control mechanism, taking into account the instrument inertia, reliable results can be achieved and measurements up to relatively large frequencies are possible.

Wednesday 18:10 Foyer Sirene

PO51

Improving commercial magnetocell designs for the evaluation of magnetorheological fluids

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Magnetorheological (MR) fluids are smart materials that exhibit anisotropic mechanical properties. In the absence of magnetic fields they essentially exhibit a Newtonian behaviour. However, when an external magnetic field is applied the viscosity increases dramatically. Measuring the rheological response of these materials under the presence of magnetic fields is not a trivial task despite the fact that there are several commercial devices capable to do so in the market. Current applications and theoretical analyses require much stronger field strengths and/or improved homogeneity levels [1]. Inspired in previous work in this field [2], in this communication we propose the use of a double-gap cell in order to enhance the field strength and to dramatically improve the homogeneity of the magnetic field in the sample. First, the device optimization is carried out using magnetostatic Finite Element Method simulations. Next, Computational Fluid Dynamics simulations are carried out and validated against experiments and theoretical calculations for Newtonian liquids. Finally, yield stress fluids are addressed and in particular MR fluids.

- [1] de Vicente, J. (2013). e-rheo-iba, 1, 1-18. [2] Laun, H. M. et al. (2010). Journal of Rheology, 54(2), 327-354.

Wednesday 18:10 Foyer Sirene

PO52

Elastohydrodynamic lubrication of shear thickening colloids

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Elastohydrodynamic Lubrication of Shear Thickening Colloids K. Shahrivar, E. Ortigosa-Moya, J. de Vicente Biocolloid and Fluid Physics Group, Department of Applied Physics, Faculty of Sciences, University of Granada, C/ Fuentenueva s/n, 18071-Granada, Spain POSTER Session e-mail of the presenter: kshahrivar@ugr.es The behaviour of complex fluids in thin films under the isoviscous elastohydrodynamic lubrication regime is a topic of current interest. Typically, a scaling master curve is found when plotting the friction coefficient as a function of the Gumbel (or Sommerfeld) number using the high shear viscosity of the fluid in the contact [1]. A vast majority of the materials used to lubricate compliant contacts are shear thinning fluids [2] and very little is known about the lubrication properties of shear thickening fluids where the viscosity increases when increasing the shear rate. In this communication, we build a tribological pure-sliding cell that operates in the soft elastohydrodynamic regime. The tribopairs are made of polydimethylsiloxane (PDMS) and the lubricating fluid is a shear thickening one. In particular, this shear thickening fluid is prepared by dispersion of corn starch in glycerol and silicone oils at different concentrations (30 and 36 vol%). We demonstrate that experimental data, plotted in terms of Stribeck curves, provide useful information on the entrainment of particles/fluid through the contact. Finally, experimental results are also compared with numerical solutions of the Reynolds equation for time-independent non-Newtonian fluids.

- [1] Wang, Y. & Wang, Q. J. (2013). Stribeck curves. In Encyclopedia of Tribology, Springer US. [2] Jang, J. Y. et al. (2007). Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences (Vol. 463, No. 2088, pp. 3271-3290). The Royal Society.

Wednesday 18:10 Foyer Sirene

PO53

Continuous fractionation of particles in viscoplastic fluidsMohammad Shanb Ghazani¹, Braz Demuner², John Kadla³, James Olson⁴, and Mark Martinez¹¹*Department of Chemical and Biological Engineering, University of British Columbia, Vancouver, Canada;* ²*Fibria Celulose, Aracruz, Brazil;* ³*Fibria Innovations, Burnaby, Canada;* ⁴*Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada*

A laboratory-scale continuous device was developed to test the possibility of fractionation of particles through use of viscoplastic fluids in a continuous method. The methodology is based on the control of threshold of motion by a balance between the driving force and the resisting force due to yield stress of a viscoplastic fluid. Ideal separation using spherical and fibre-shaped nylon particles are presented along with speculative discussions of the observed trend behavior. This methodology is also demonstrated on a novel class of materials emerging in industry, namely microfibrils. The results collected align with those of obtained from batch-wise method, promising the application of the device for fractionation of industrially available particle systems.

Wednesday 18:10 Foyer Sirene

PO54

Simultaneous measure of temperature and velocity in fluids using MRISebastien Leclerc¹, Christel Metivier¹, Mohamed Darbouli¹, and Didier Stemmelen²¹*LEMTA, Nancy, France;* ²*LEMTA, Vandoeuvre-Les-Nancy, France*

The Rayleigh-Bénard convection (RBC) is a buoyancy driven instability in a fluid layer confined between two horizontal walls. The RBC in Newtonian fluids has been extensively studied since more than a century. These last decades, a growing interest has emerged for non-Newtonian fluids, mainly due to the wide fields of applications (e.g. oil, cosmetic, pharmaceuticals, food industries). As it is possible to measure with the same technique various physical quantities such as temperature or velocities, MRI is an interesting tool to study the RBC. Nevertheless, if velocity measurements using MRI are common in engineering sciences [1], temperature measurements with this technique are seldom used outside the medical field. In this study, we compare the various MRI thermometry techniques: phase mapping, diffusion coefficient measure, relaxation. The first one is the method of choice in medical studies but is not usable in our case due to the experimental conditions. On the contrary, the last method seems suitable for our study. We present the validity of this method on a model Newtonian fluid, the glycerol. We show that for a conductive regime, temperature measurements are in very good agreement with the theoretical profile. In the convective regime, when comparing the temperature and velocity fields obtained by MRI, we get an excellent agreement in terms of flow structure. Temperature uncertainties are found to be less than 1°C for all our results. MRI thermometry and velocimetry [2] have also been tested on a xanthan solution, a shear-thinning fluid. As this aqueous solution has relaxation times very different from the glycerol, new problems have arisen when measuring temperature. We present a way to overcome them as well as some resulting temperature maps.

[1] Callaghan, P. T. (1999). Reports on Progress in Physics, 62(4), 599. [2] Darbouli, M. et al. (2016). International Journal of Heat and Mass Transfer, 95, 742-754.

Wednesday 18:10 Foyer Sirene

PO55

Effect of drying and grinding characteristics of colored potato (*Solanum tuberosum* L.) on tribology of mashed colored potato paste

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The mouthfeel of mashed potato prepared with steamed purple flesh potato (SPFP) was investigated by measuring tribological and rheological characteristics. Mathematical models describing pre-processes such as drying and grinding associated with physical properties of mashed potato were also explored. The effect of drying temperature (60, 70, 80, and 90 °C) on quality changes (moisture and anthocyanin content) of SPFP was successfully described ($R^2 > 0.9583$). The sigmoid model was suitably applied to estimate particle sizes of dried SPFP during grinding ($R^2 > 0.9864$). As the particle size of mashed SPFP increased, friction coefficient increased, and storage and loss modulus decreased. Taste, smoothness and after-feel sensation were increased as particle sizes decreased, while appearance and odor showed no significant differences. To predict the sensory property using tribology and rheology, the specific conditions were successfully determined ($R^2 > 0.9926$).

Wednesday 18:10 Foyer Sirene

PO56

Multifractal approaches of the ring tensile rupture patterns of dried laver (*porphyra*) as affected by the relative humidity

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The effect of water activity (a_w) or the relative humidity (RH) on the tensile rupture properties of dried laver (DL) associated with structures formed with phycocolloids was investigated. The morphological characteristics of tensile ruptured DL samples at various relative humidities were evaluated by multifractal analysis. The RH of the microclimate was controlled from 10 to 90% at 25 °C using supersaturated salt solutions. The sorption isotherm of DL was experimentally obtained and quantitatively analyzed using mathematical models. The monolayer moisture contents from the GAB (Guggenheim-Anderson-de Boer) model was 5.92% (w.b.). An increase in the RH resulted in increasing ring tensile stress and maintaining constant ring tensile strain up to 58%-75% RH, whereas the ring tensile stress and the ring tensile strain rapidly decreased and increased, respectively, when the RH was higher than 75%. The general fractal dimensions and the multifractal spectra $f(a)$ manifested that the patterns of the lowest and the highest moisture content of dried laver showed high irregularity. The different multifractal parameters obtained from the DL at various RHs well-represented the transient moment of the structures from the monolayer moisture to texture changes associated with RH. Overall, the ring tensile test and the multifractal analysis were useful tools to analyze the change of crispness of DL from its structural

characteristics. In addition, the results of this study revealed that the integration and disintegration properties of DL occurred through the networks of phycocolloids at various moisture contents.

Wednesday 18:10 Foyer Sirene

PO57

Rheology of the microencapsulation of gallic acid with Aloe vera mucilage (*Aloe barbadensis* Miller) by spray drying

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The microencapsulation by spray drying (SD) of gallic acid (GA) with mucilage of Aloe vera (Av) as an alternate encapsulating agent was studied. Microstructure of undamaged spherical granules was observed by SEM microscopy for both Av and maltodextrin (MD) capsules. The particle size distribution from the Av mucilage samples exhibited a quasi-modal distribution unlike the GA samples, which showed a bimodal distribution. Samples of Av containing GA were characterized by infrared spectroscopy and typical absorption peaks of the active compounds were observed. Gallic acid peaks were not observed in the expected wave number ranges of the spectrum, indicating a possible encapsulation of GA. In the antioxidant capacity evaluation, results showed that encapsulated GA retains its capacity due to a short contact time in the SD (<5 s). The behavior in steady simple shear flow of the reconstituted mucilage samples evidenced non-Newtonian shear-thinning characteristics. In linear oscillatory shear tests, it was observed that the viscous component (G'') predominated over the elastic counterpart (G'). Comparing the release profiles of the micro particles obtained from the SD, a difference is observed in the maximum release time for the GA, as well in its release yield percentage; being greater in both cases for the microcapsules based on the Av mucilage.

Wednesday 18:10 Foyer Sirene

PO58

Rheological properties evaluation of bread dough with different levels of fermented whey

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Whey is the by-product of cheese production, containing some important components such as lactose and protein. Considering its nutritional value, whey is an excellent raw material for the development of other food products, in line with the concept of circular economy. The controlled fermentation of the whey generates bioactive compounds that can be explored as an added value ingredient, when incorporated into a staple food, as bread. This work is part of a project that aims to optimize the healthy bread composition and technological processing, in order to maximise its anti-inflammatory and antimicrobial potential. The main objective of this work was to evaluate the maximum content of fermented whey to be incorporated in traditional bread production, without any damage to the structure of the bread dough, keeping the palatable and sensory appealing bread characteristics. The serum was fermented for 6 days at 37°C ± 2 in an air circulating vase and then characterized in terms of centesimal composition (proteins, lipids, ashes, carbohydrates and dry matter). Different levels of incorporation of fermented whey were tested in a bread formulation already developed in previous studies. The doughs were characterized in terms of pH, extensibility, texture and mechanical spectra obtained under SAOS, before and after fermentation. In the loaves, physical chemical analyzes were performed: acidity in lactic acid, pH, ash, fat, water activity, color and texture (TPA). The effect of adding whey to the appearance of the bread crust was also monitored and some preliminary tasting tests were performed. It was verified that the serum presents high bioactivity after fermentation and affects the rheological and texture properties of the bread. Nevertheless, it is possible to optimise a bread formulation with sensory properties similar to traditional bread, but with an incremented bioactivity, having great potential for possible further development and commercialization.

Wednesday 18:10 Foyer Sirene

PO59

Impact of cell disruption on rheological properties of wheat bread with *Chlorella vulgaris* incorporation

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Microalgae are one of the most promising sources of polyunsaturated fatty acids, proteins, polysaccharides, pigments, antioxidants, with impact on the nutritional and sensory properties of food. The use of *Chlorella vulgaris*, the most common microalgae (EFSA approved), as a functional ingredient can impart structure modifications. The cell wall of *Chlorella* varies among species and strains and also depends on growth conditions. Generally, the inner cell wall has high cellulose content and the outer cell wall may include algaenan which is a highly resistant aliphatic polymer. Microalgae compounds are naturally encapsulated within microalgae cells, being able to resist harsh technological conditions during food processing. However, toward application of algae biomass in food, cell disruption could be required to increase the bioavailability of algae constituents. This work is part of a project that intends to explore microalgae potential to be low-carbon-footprint healthy ingredients for future foods. It aims to increase nutritional quality of bread by addition of microalgae biomass, while maintaining a high sensorial quality. *Chlorella vulgaris* biomass was pre-processed using different cell disruption methods, including microwave irradiation and bead milling. The morphological changes on the cells were observed by optical microscopy and SEM. Rheological properties of wheat based doughs and breads prepared with addition of these pre-processed microalgae (3% w/w) were investigated. The impact of disruption on the bread bioactivity, such as antioxidant

capacity and phenolic compounds content, was also studied. Doughs were characterized by empirical rheology methods (farinograph AACC 54-21.02, alveograph AACC 54-30.02 and texturometer - penetration and extensibility tests) and by fundamental SAOS rheology (frequency sweeps after fermentation). In the loaves, water activity, colour and texture profile analysis (TPA) during the aging process was used to investigate the impact of cell disruption methods.

Wednesday 18:10 Foyer Sirene

PO60

Evolution of rheology behaviour of Miso from obtained from yeast starters under standardized conditions

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Fermentations are traditional methods of food processing. They include, but are not limited to, well known fermented foods and seasoning obtained from the fermentation of protein-rich legumes like miso paste and shoyu. Miso, a fermented Japanese food, is produced from steamed rice, cooked soybeans and salt, through the action of moulds, yeasts and lactic acid bacteria. Miso is richer in minerals and vitamins and presents lower levels the anti-nutritional factors common in pulses. It is a viscoelastic gel, generally used as a base to prepare soup. In the present work, the production of an innovative grass pea miso was investigated. This new food can contribute to the diversification of healthier and more nutritious diets and to increase legume consumption. Grass pea (*Lathyrus sativus* L.) is a robust grain legume with high nutritional value that can be used to produce miso, using Eastern methodologies based on the activity of eukaryotic probiotic strains, under controlled conditions. Standardized inocula of *Aspergillus oryzae* spores and two different yeast strains (*Candida versatilis* and *Zygosaccharomyces rouxii*) were used as starters, to produce three types of miso using grass pea as raw material. Miso produced from soybeans was also produced, as a reference. The texture characterization (TPA - texturometer) and linear viscoelastic behaviour (SAOS) of three types of miso were evaluated along the fermentation process. After 1 month of fermentation, the firmness of the different types of miso significantly decreased. However, this reduction is more pronounced in the case of miso produced from grass pea and with *Z. rouxii*. In grass pea miso the macromolecule structuring level, expressed in terms of Plateau Modulus, decreased in all the cases, over time. However, for the soybean systems, an increase of the viscoelastic functions and consequently of the Plateau Modulus was observed, revealing a different role of the macromolecules on the development of the miso gel network.

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PO61

The role of rheology in the cosmetic industry: a powerful instrument for the management of the scale up process of emulsions

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Rheology is a helpful instrument for the formulation and the characterization of cosmetic products. It can play a significant role in defining and controlling the in-use performance, the stability and the aesthetic properties of formulations. Unifarco S.p.a, the leading company in Italy for the sale of cosmetic products in pharmacies, has recently introduced the systematic use of rheology to provide support to the R&D department, the quality assurance department and the industrial processing. The aim of this study, made in collaboration with the Cosmetology laboratory of DSF - University of Padua, was to use rheology as a suitable tool to support the scale up process during the industrialization phase. The passage from the pilot scale of R&D (some dozens of kilograms) to the industrial scale (some thousands of kilograms) can be problematic and can introduce some deviations that can negatively affect the physical properties of the final product. The deviations may be related to the hydration time of polymers, to the solubilization of active ingredients, or to the cooling mode. Generally, due to these deviations, the greater the amount to be processed is, the lower the viscosity and the viscoelastic moduli of the formulations are. The rheological properties of two emulsified systems produced on different scales at Unifarco S.p.a are investigated in this work. In one case, the scale up process has not significantly modified the rheological properties. In the second case, instead, some changes have been introduced into the usual manufacturing protocols on the basis of the analysis pointed out using the rheometer, as to make the differences between the pilot scale and the industrial scale negligible. The results confirmed that rheology is a valuable tool to identify any negative changes in the properties of the emulsions and to optimize the industrial processing, suggesting little changes to be included into the manufacturing protocols.

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PO62

Rheological study of polymeric ingredients as texturizers for cosmetic products

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The development of new formulation systems able to satisfy the multisensory expectations of the consumers represents a growing marketing trend in the cosmetic industry. Hydrophilic polymers, thanks to their ability to coordinate water molecules and form a three-dimensional network, are among the most widely used raw materials not only as thickeners and rheological modifiers, but also as enhancers of smoothness, spreadability and texture of a product. The aim of this work was to study the rheological behaviour of two polymeric raw materials recently proposed on the market: STRUCTURE® XL (Hydroxypropyl starch phosphate) and ADEKA NOL GT-730 (PEG-240/HDI copolymer BIS-decyltetradeceth-20 ether, Butylen glycol, Water, Potassium laurate, Tocopherol). The first one is a powder of a chemically modified maize starch, the second one is a blend containing a block copolymer, whose units are linked by urethane bonds. Firstly, the rheological profiles of gel systems, prepared dissolving each polymer in water at different concentrations, were obtained both in continuous and oscillatory flow conditions. As expected, according to the different chemistry

of the polymers, the data pointed out two opposite rheological properties: the urethane derivative showed a viscoelastic profile (frequency sweep) and a liquid like behaviour (creep test), while the starch derivative showed a gel like pattern of G' and G'' in function of frequency and significant solid like properties at concentration $> 4\%$ (w/w). Therefore the binary associations were characterized as such or formulated in oil in water emulsions. The results have allowed to identify the best concentrations of STRUCTURE® XL and ADEKA NOL GT-730, which, combined in appropriate ratios, can give very different textures and can enhance the sensory profile of a cosmetic product. Rheology turned out to be a valid instrument for the study of the structure properties and flow behaviour of cosmetic systems and a powerful tool for the cosmetic design of new products.

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PO63

Textural properties of sorghum – cowpea based high protein gluten free pasta

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High protein pasta composed of blends of sorghum and cowpea flour was optimized to obtain a strong and elastic product with the aim of producing a gluten free pasta. Low temperature extrusion process was performed in a single screw extruder. Textural and microstructural properties of eight different mixtures of sorghum - cowpea based pasta were evaluated. The mechanical properties of pasta result analysis with respect to the modulus and firmness of cooked pasta shows that the value of Young's modulus of the cooked pasta was lowest for sample 4, 0.09 MPa and highest for sample 2, 0.31 MPa. A compression test is very important for spaghetti cooking quality because it defines the resistance of the spaghetti to deformation; correlating to chewing during mastication. The value of the pasta firmness was lowest for samples 3, 0.28 N and highest 0.86 N for sample 6 respectively. From our study it shows that increase in ratio of cowpea flour which implies increase in protein content and level of pregelatinized cowpea increased the firmness of the pasta. Careful observation of the result shows that pasta samples containing higher values of cassava flour showed relative drop in their firmness, higher amounts of cassava starch in the pasta formulation means less protein ratio since cassava flour mainly consists of starch. The breaking strength load value of the dry pasta shows that breaking stress expressed (represent index of toughness of material like pasta). Sample 2 recorded the breaking stress value of 16.5 MPa while sample 8 recorded the least value of 12.88 MPa. The result of microscopy analysis showed that the extrudates was composed of a continuous protein network in which starch granules was dispersed. The protein contents of the samples ranged between 17.33 - 18.60 %. As earlier mentioned this toughness could be attributed to the formation of a more compact protein matrix in the pasta which might be said to be responsible for its greater resistance to fracture.

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PO64

The influence of thermal sterilization on phase transition kinetics of chitosan hydrogels

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Chitosan, as a natural biopolymer, a substance with biocompatible and biodegradable properties, has found a wide application in medicine, food and cosmetics. Chitosan solution requires sterilization before using it in different applications. The most common type of sterilization is the thermal process during which changes of chitosan molecular weight may occurs. This can lead to changes in the temperature of the phase transition and kinetics of the gelation process. The aim of this study was the a comprehensive characterization of the influence of thermal sterilization on molecular weight and phase transition kinetics of chitosan solutions used in pharmaceutical industry and cell culture. Rheological measurements were made for four types of chitosan with different molecular weights using two methods of substrate preparation - with the addition of a crosslinking agent before and after the sterilization process. The molecular weight was determined by intrinsic viscosity measurements of crab chitosan and shrimp before and after the thermal sterilization process. It has been found that sterilization process has a significant influence on the molecular weight of chitosan, what is critical in the application of this biopolymer in medicine and pharmaceutical industry due to its effect on gelation kinetics, mechanical strength and biological activity of formed hydrogel. The time needed for the three-dimensional hydrogel structure formation is shortened after sterilization. It was confirmed that the stage at which the crosslinking agent is added to the system has a crucial influence on the sterile product characteristic (dominance of elastic or viscous properties). It was also found that performed simulations of the sterilization process in the rheometer measuring system accurately reproduces with the actual sterilization process commonly conducted in the preparation of chitosan thermogels.

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PO65

The influence of shear rate on the structural and viscous properties of chitosan colloidal system investigated by Rheo-SALS technics

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Chitosan is a derivative of chitin, a polysaccharide that is a component of the crustaceans shells. Chitosan, as a natural biopolymer, a substance with biocompatible and biodegradable properties, has found a wide application in medicine, food and cosmetics industries as well as in wastewater treatment processes. The study presents shear rate effect on viscous and structural properties of chitosan colloidal system with addition of disodium β -glycerophosphate as a crosslinking agent. The measurements were conducted in a double-gap system of a rotational rheometer Anton Paar Physica MCR 502 coupled with SALS (small angle light scattering) system. Specially designed, glass parts of measuring system enabled to simultaneous measurement of rheological properties and light scattering data. As the light source a diode laser operating at a wavelength 658 nm was used. The viscosity was determined during equilibrium test, in which the sample was sheared for 60 s at subsequent constant shear rates in the range from 1 to 500 s⁻¹. The investigated chitosan system reveal a shear thinning behavior. Simultaneously, as a viscosity decreases, the anisotropy of

scattering pattern can be observe - the initial circle shape becomes more elliptical. The elliptical shape of scattering pattern, oriented perpendicular to shear flow direction, is the result of the molecules stretching along the flow direction. These changes represent the orientations and deformations of the polymer particles. Based on the eigenvalues of the second-order tensor of the intensity distribution, it was possible to quantify the anisotropy parameter. Analysis of the dependence of anisotropy on the shear rate shows two regimes delimited by critical value of shear rate. This phenomenon is impossible to observe analyzing only the classical rheological data obtained from rotational rheometer.

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PO66

The Rheo-SALS study of the sol-gel phase transition of chitosan colloidal system - the effect of temperature and concentration

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Chitosan is an amino-polysaccharide obtained by deacetylation of chitin. Due to its biocompatible and biodegradable properties, chitosan has a variety of applications in the field of medicine, food and cosmetics industries. The applications of chitosan systems as scaffolds in tissue engineering and in smart drug delivery systems are the subject of many studies in the recent literature. The aim of this study was the investigation of thermal-induce phase transition process of chitosan colloidal systems. The effect of chitosan concentration on gelation process was also examined. The measurements were conducted in a plate-plate system of a rotational rheometer Anton Paar Physica MCR 502 coupled with SALS (small angle light scattering) system. The gelation process was conducted in non-isothermal conditions with a constant heat rate of 1 K/min and fixed values of amplitude and angular frequency. Based on the results, differences in the gelling process was observed depending on the polymer concentration. The higher the concentration of chitosan, the higher level of values of the dynamic moduli in the initial phase of the process and the lower temperature of gel point. With the change in the concentration of chitosan, differences in the intensity distribution of scattered light were also observed. The maximum intensity plateau is shifted towards the higher values of the q-vector with increasing concentration. Analysis of the light scattering data using different models (Zimm or Porod plot for instance) allow to state that during the gelation process, conformation of chitosan molecules changes from collapsed or Gaussian coil to more swollen form. The time-dependence of intensity at fixed q-vector enable to determine the gel point and compare it with a gel points determined by different rheological methods.

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PO67

The sol-gel phase transition and viscoelastic properties of thermosensitive chitosan hydrogels with calcium β -glycerophosphate

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Thermosensitive chitosan hydrogels are of interest to many researchers because they are a less invasive form of scaffolds used in tissue engineering. This is due to the formation of scaffold in vivo and better filling of the irregular defect. In order to lower the gelation temperature to physiological conditions, the only material used for injectable scaffolds preparation is sodium β -glycerophosphate. No studies were found in which the sodium salt was completely replaced by another glycerophosphate salt. The calcium glycerophosphate salt was used to improve the mechanical and functional scaffold properties in order to successfully apply them e.g. in bone tissue engineering. As experimental media 2% (w/v) colloidal solutions of chitosan with the addition of four different concentrations of calcium β -glycerophosphate - as a substance supporting the gel forming process at 37 °C under physiological pH conditions - were used. The viscoelastic properties and the sol-gel phase transition conditions were determined using oscillatory shear. Mechanical properties of investigated solutions were determined at constant and variable strains in non-isothermal conditions in the temperature range of 5 °C - 60 °C. During the study, it was found that the use of identical concentrations of different glycerophosphate salts did not provide identical viscoelastic properties and gelation conditions. It is worth noting that the tendency of gelation temperature as a function of concentration is similar to that of sodium glycerophosphate, however with much lower gelation temperatures. Only scaffolds containing 0.5g of salt underwent sol-gel phase transition at conditions similar to body temperature. Such hydrogels also showed similar viscoelastic properties to the common injectable scaffolds prepared with sodium β -glycerophosphate.

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Wednesday 18:10 Foyer Sirene

PO68

Influence of mechanical deformation on the gelation phenomenon of colloidal chitosan solutions

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Colloidal solutions of chitosan have the ability to undergo a sol-gel phase transition induced by the changing of temperature. This creates the possibility of producing less invasive injection scaffolds. In this case, it is extremely important to precisely determine conditions of the sol-gel phase transition. The most commonly used method for determining the gelation point temperature is to carry out non-isothermal rheological measurements in the oscillation mode. The advantages of these measurements are their low invasiveness and simplicity of interpretation of the obtained results. The long-chain chitosan occurs in solution as the entangled coil

with a solvation shell. During heating undergoes the disentanglement of polymer chains and leads to the interaction between functional groups. It is therefore possible, that the rotational shear can accelerate the gelation process by forcing the biopolymer chains to straighten out. To determine the impact of the mechanical deformation on gelation process, rotational and oscillatory measurements of colloidal chitosan solutions in isothermal and non-isothermal condition were carried out. The value of the applied shear rate was calculated based on values of the angular frequency and the strain amplitude in oscillatory measurements. As experimental media 2% (w/v) colloidal solutions of chitosan with the addition of disodium β -glycerophosphate were used. The obtained experimental data allowed to conclude that the use of the same deformation values, in the case of rotational measurements leads to achieving higher values of dynamic viscosity compared to real part of complex viscosity. This may prove stronger crosslinking of the biopolymer under study. Simultaneously, the obtained experimental results indicate faster changes taking place inside the tested structure.

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PO69

Dynamic rheology of kuzu starch-galactomannan pastes

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Kuzu (kudzu) is a plant of *Pueraria* genus widely used in traditional Chinese medicine. Kuzu cures flu, fever, nausea, migraine, allergies, diseases of upper respiratory tract, obesity, and problems with stomach-intestinal ailments. It also affects the cardiovascular system by lowering blood pressure, increasing economization of heart beat, and reducing the risk of heart attack. Starch extracted from kuzu root is unique because of the content of bioactive isoflavones (mainly daidzein), so it could be an ecological and healthy alternative to thickening and binding agents such as potato starch or gelatin. The rheological properties of kuzu starch can be modified using hydrocolloid polysaccharides as additives. The aim of this study was a comprehensive characterization of rheological properties of kuzu starch-galactomannan pastes depending on the concentration of galactomannan ($0 \div 0.3\%$ w/v) and the galactose-to-mannose ratio in galactomannan molecule (fenugreek gum [1:1], guar gum [1:2], tara gum [1:3], and locust bean gum [1:4]). Conducted rheological measurements included the determination of storage and loss moduli $G'(\omega)$ and $G''(\omega)$ within the range of linear viscoelasticity. The obtained dynamic data were described by the new modified fractional Kelvin-Voigt model with two Scott-Blair elements (springpots) connected in parallel. The model allowed to determine 17 rheological parameters providing a lot of additional information about structure, texture and viscoelastic properties of binary pastes in comparison to the classical analysis of oscillatory tests.

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PO70

The influence of phosphate salts on rheological parameters of model poultry hams

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The effect of concentration and type of phosphate salts on the solubilization of muscle proteins and subsequent formation of pre-gel by proteins and added water were investigated. The progression of gel structures was monitored during temperature rising (from 5 up to 70 °C) and subsequent cooling (from 70 to 5°C) by measuring the changes in viscoelastic properties. Prepared samples consisting of chicken lean meat, drinking water and sodium chloride contained phosphate salts concentrations at the grade of 25 and 50 % of the highest permitted amount of phosphorus pentoxide. The changes in the values of the elastic and loss modulus were measured along with the phase angle value and the results were compared with the values of the control sample containing only sodium chloride. It has been found that the type of phosphate used had a major influence on the quality of the gel structures expressed as the content of tightly bound water.

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PO71

Effects of dispersing conditions on rheological properties of dietary fibre aqueous systems

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Dietary fibres can be considered as carbohydrate polymers (with three or more monomeric units) which are neither digested nor absorbed in the human small intestine and have beneficial physiological effects, such as a decrease in intestinal transit time, a reduction in blood total cholesterol, in blood LDL cholesterol levels, etc. In addition to their health effects, it is well known that they modify also the rheological properties of the system, exhibiting thickening and/or structuring effects, according to the concentration and processing conditions. Therefore, when they are added to improve the food nutritional level (also following the current WHO suggestions) they could modify the final consistency; consequently, the knowledge of their technological effects on food texture is relevant to guarantee both the desired nutritional value and the expected consistency. In this work, the effects of dietary fibre were investigated in simple systems based on fibre dispersed in water at different conditions. Particularly, homogenization rate and process time were modified using a constant fibre concentration; obtained systems were investigated with steady and dynamic tests aiming at determining the rheological properties of these dispersions. It was observed that both dynamic moduli and viscosity are significantly affected by operating conditions. Modifying these process parameters, in addition to fibre concentration, rheological properties can be tuned according to the specific application (e.g. emulsion, sauce, beverage, etc.).

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PO72

Characterization of hyaluronic acid in saline environment by DLS micro-rheological and conventional rheological measurements

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Hyaluronic acid (HA), a naturally occurring biopolymer shows very interesting properties for several clinical applications; particularly, it is mostly used as viscosupplements in its orthopaedic and ophthalmic capacity and as fillers in cosmetic industry. In solution, with HA being a polyelectrolyte, the polymer chains behave like semi-rigid and stiff sticks in water, while in saline environment they take on the form of expanded random coils. Solutions of HA are extremely lubricant and very hydrophilic, showing very interesting rheological properties: the polymer chains tend to entangle with each other even at relatively low concentration, significantly affecting the rheological properties, displaying a shear-thinning behaviour, i.e. a shear rate dependent viscosity and while they act as viscous liquid at low frequency, they show elastic behaviour at higher frequency. In the present work, a detailed rheological characterization of HA in a saline environment was conducted, studying both the molecular weight (over the range of 90 to 4000 kDa) and the concentration dependence (over the range of 1 to 20 mg/mL) in order to better evaluate their behaviour and suitability of applications. Standard viscoelastic and flow characterization techniques were coupled with micro-rheological measurements, i.e. by measuring the passive motions of particles, embedded in the material, due to thermal or Brownian fluctuations via Dynamic Light Scattering (DLS), where the use of small colloidal particles effectively extends the accessible frequency range (0.01-10000 Hz) typical of standard rheometers. Moreover, the mesh size ξ referring to the physical network created by the polymer chains, was calculated using the elastic modulus measured within the rubbery plateau region; values ranging from 200 to 700 nm were obtained.

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PO73

The impact of the hummus structure and rheological properties on glycaemic response in humans

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As the prevalence of type 2 diabetes has risen, the consumption of legumes has declined. Evidence suggests that legumes play an important role in blood glucose control. It is thought that food structure and rheological properties are vital to the digestion of food and absorption of nutrients. However, the physiological mechanisms remain unclear. In this study, we explain the importance of legume structure by using two chickpea hummus meals: blended whole chickpea (WH) in which cells remain intact, while the other made with flour (FH) where the cells are ruptured. A rheometer equipped with a parallel plate geometry is used to assess rheological properties for both meals. Light microscopy is used to examine samples to assess structure and particle size. A randomised cross-over study was conducted to measure glycaemic and insulinaemic responses. On each study visit, a cannula is inserted and a carbohydrate-controlled test meal (for WH and FH content) was served as breakfast. All venous blood samples were collected postprandially. Both meals had similar rheological properties showing a gel-like behavior, with the storage modulus (G') greater than the loss modulus (G'') throughout the linear viscoelastic range, which can be explained by the weak network formation by hummus particles aggregates. However, at 30-minute, post-meal blood glucose level was significantly higher for FH compared to WH ($P=0.03$). Furthermore, blood insulin level was lower after the consumption of WH compared to the FH ($P=0.031$). These results can be explained by the different cellular structures observed in microscopic images. The structure in WH contains clusters of entrapped starch granules within intact plant cells, hence, larger particle size, while FH contains ruptured cells with free starch granules, which are more susceptible to digestion. To our knowledge, this study is the first study to investigate the relationship between the food structure, rheological properties, and the glycaemic responses observed in a human clinical trial.

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PO74

Rheological characterization of cuttlefish ink based food products

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Cuttlefish ink is worldwide used as a food flavoring and ingredient, because of its peculiar sensory properties. It is composed by different constituents, including a complex biopolymer, the melanin and other chemical species such as tyrosinase, catecholamines and others [1]. Its industrial manufacture is in general addressed by diluting with water the fluid extracted from the ink sac. Texture stabilizers can also be added, in order to hinder the occurrence of long term phase separation, which is detrimental for the quality and the marketability of the commercial product. Then, the resulting blend is subjected to a thermal treatment to obtain the commercial sterility. The final product is eventually a water/ink mixture with presence of emulsifiers, such as the Xanthan gum. Amplitude and frequency sweep measurements are carried out on different samples of the final product by using an Anton Paar MCR102 rheometer equipped with a 50 mm parallel plate fixture. The influence of different factors on the rheology is investigated: (i) the water/ink ratio; (ii) the thermal treatment; (iii) the presence/absence of emulsifiers; (iv) the Xanthan gum concentration. It was found that cuttlefish ink behaves as a non-Newtonian fluid with a pronounced elastic behavior characterized by G' values always greater than G'' . This is likely due to the presence of melanin in the product. Furthermore, G' increases significantly with the thermal treatment and the presence of Xanthan gum. On the other hand, the emulsifier concentration does not significantly influence the rheological properties, at least for the values here investigated. Frequency sweep measurements are analyzed by means of the weak-

gel model [2]. To conclude, the rheological characterization of the cuttlefish ink based products demonstrates to be a valuable tool to infer and quantify quality indexes of the product such as texture, creaminess and others.

[1] Derby, C. D. (2014). *Marine drugs*, 12(5), 2700-2730. [2] Gabriele, D. et al. (2001). *Rheologica Acta*, 40(2), 120-127.

Wednesday 18:10 Foyer Sirene

PO75

Additive electrospraying for nanomedicine: optimizing antibiotic loaded chitosan nanoparticles to design antimicrobial platforms

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Nanotechnologies based on the use of integrated approaches currently may offer an efficacious support to the management of microbial infection, opening new interesting opportunities and perspectives in antimicrobial nanomedicine. An interesting approach certainly concerns the mixing of nanoparticles and fibres for the fabrication of integrated drug loaded platforms. Herein, it is proposed the optimization of electrosprayed chitosan (CS) nanoparticles entrapped in electrospun Polycaprolactone (PCL) matrices, to fight local oral inflammatory events by the antibiotic release. In this work, we investigate best process conditions to fabricate drug loaded nanoparticles and to integrate them in the fibrous network. SEM/TEM analyses have been used to investigate morphological properties of carriers. The size of particles is mainly influenced by changes in process parameters (i.e., voltage, flow rate), while shape factor is attributed to changes in viscosity of the CS solution. Secondly, the retention effect due to the hydrophobic behavior of PCL fibres also influences drug release as a function of different nanoparticles/nanofibers assembly, with effects on the antibacterial properties.

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PO76

A Study on the Mechanical Relaxation under Heating of Parmigiano Reggiano cheese

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Parmigiano Reggiano cheese (PR) is an Italian cheese for which the European Commission deserved the protection of designation of the origin and imposed quality requirements about the time of ripening, granular structure, and fracture properties. Aiming to individuate material properties that behind objectively law requirements, PR cheeses having different structure and different ripening time have been investigated for their microstructure and thermo-mechanical properties by coupling microstructure, rheological and thermal supporting data. At microscopic scale, cheese matrix shows dispersed salt crystals aggregates, randomly dispersed macro-discontinuities previously generated from partially-fused curd junctions and a wide spread spongy microstructure, likely originated by gas-producing microorganisms during making process. At sub-microscopic scale, PR cheese shows a dense casein network entrapping low-density regions consisting of both non-globular fat and globular fat. Creep behaviour of PR cheese was modelled by using a six-parameter rheological model, consisting of one Maxwell and two Kelvin rheological in-series elements accounting for the alone and combined contribute of the dispersed phases to the total deformation. The elastic modulus during instantaneous deformation; the two retardation times during viscoelastic relaxation; and the Newtonian viscosity at the steady-state deformation rate were determined from the best-fit. The linearized Arrhenius plot of steady-state deformation rate was analysed showing two main apparent creep activation energies ranging from 10 to 81 J/Kmol; while, the thermal profiles show some melting phenomena between 0° and 60°C. The lower activation energy was attributed to the dislocation of macro-discontinuities and micro-porosity. The higher activation energy suggested a mechanism transition towards the sliding between the physical interfaces between casein (harder regions) and lipid (soft regions) due to the progress of fat melting.

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PO77

Impact of fibrinogen concentration on clotting kinetics and shear stiffening of whole blood clots

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Background: Blood is a complex fluid with the ability to solidify in response to physiological or pathological triggers. Disorders of haemostasis play an important role in global morbidity and mortality. Kinetics of coagulation and material properties of the final clot depend on the structural composition of blood. Rheometry is known to be a sensitive tool to monitor coagulation and can also be used to analyse material properties in response to increasing shear strain. Methods: Whole blood clots of healthy human volunteers were formed in the Anton Paar MCR302 (plate-plate system, $d = 1\text{ mm}$). Fibrinogen was added to sample aliquots to yield samples with medium and high fibrinogen concentration. G' was monitored until plateau formation ($f = 1.5\text{ Hz}$, shear strain $= 0.01$), at which point the amplitude sweep was started by logarithmically ramping up shear strain to 300. Results: Fibrinogen concentration in the sample groups (BL, medium, high) was $254 \pm 45\text{ mg/dl}$, $597 \pm 185\text{ mg/dl}$ and $812 \pm 282\text{ mg/dl}$. Clots in medium and high groups showed decreased clotting times (BL: $630 \pm 66\text{ s}$, Med: $411 \pm 100\text{ s}$, High: $295 \pm 77\text{ s}$), faster clot formation rate and higher G' at plateau (BL: $282 \pm 27\text{ Pa}$, Med: $446 \pm 81\text{ Pa}$, High: $575 \pm 122\text{ Pa}$). In response to increasing shear strain, clots showed a triphasic response: linear viscoelasticity, apparent shear softening and shear stiffening, the extent of which was correlated with fibrinogen concentration ($r = 0.77$, 95% CI [0.53, 0.9]). Discussion: Altered clotting kinetics and clot properties could be clinically important in patients with e.g. pregnancy or infectious disease. Apparent shear softening during amplitude sweep was initially surprising, however we argue that this is an artifact due to shear strain being imposed in oscillation with repeated passes of zero position, which weakens fibrin strands. However, further studies involving more advanced testing protocols are necessary to validate this hypothesis.

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PO78

Optimization of electro-fluid-dynamic process for drug loaded cellulose based capsules making in oral deliveryVincenzo Guarino¹, Rosaria altobelli¹, Paola Calcagnile², Sergio Caserta³, Tania Caputo¹, Christian Demitri², and Luigi Ambrosio¹¹*Institute of Polymers, Composites and Biomaterials, National Research Council of Italy, Napoli 80125, Italy;*²*University of Salento, Lecce, Italy;* ³*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

In the last years, hydrogels have been largely engineered in the form of capsules and/or particles at the micro and sub-micrometric size scale, to design innovative drug delivery systems with peculiar properties (e.g., swelling, pH response) for controlled molecular release. Herein, we report the development study of cellulose based microdevices for oral delivery applications, fabricated via electrodynamic atomization - an emerging electro-fluid-dynamic technology to micro-size polymer solution by the application of electrostatic forces. Process parameters have been set in order to optimize particles morphology in terms of size distribution and shape. Moreover, rheological analyses have been performed in order to identify the best solution properties for the atomization process. The evaluation of viscoelastic parameters and viscosity will allow implementing a new setup configuration for the fabrication of new core shell devices with improved encapsulation and drug release.

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PO79

Rheological properties of gluten free bread doughs under small deformation tests and possible application of strain-rate frequency superpositionYi Ren and Tim Foster*Division of Food Sciences, The University of Nottingham, Loughborough LE125RD, United Kingdom*

Dough rheology is frequently highlighted in studies of bread and relevant quality prediction and small amplitude oscillation tests are widely applied in the investigations on gluten free (GF) doughs. Currently, GF bread is mainly produced by alternative flours which are mostly a blend of non-wheat flours and, in most cases, hydrocolloids, e.g. methylcellulose (MC) showing properties of a viscoelastic liquid, and psyllium showing gel properties. In this study, water-flour system and water-flour-hydrocolloid systems were tested as basic models for GF doughs. In addition, the majority of the dough structure is developed during proving with low strain rate. Therefore, to understand the properties of these dough models and their relaxation times, an attempt has been made to apply strain-rate frequency superposition (SRFS). It involves large amplitude oscillation sweep which shifts the G' - G'' crossover to a higher frequency and, therefore, allows access to the relaxation time and minimises the influence of long-timescale phenomena. In frequency sweep tests, both hydrocolloids systems increased in moduli and MC system showed an increase in the viscous portion. Among three samples, the psyllium system showed less dependence on frequency. Interestingly, the flour-water system showed an increase in both moduli at lower frequency which might because of continuous hydration and swelling of starch granules, decreased structure breakdown (low shear rate), and longer recovery time (low frequency). In SRFS tests, the pronounced relaxation peak was not seen and the results can be influenced by noise and other factors. Therefore, the shifts were performed mainly based on maximized overlaps of complex viscosity taking the relation between both moduli, and angular frequency into consideration. The obtained relaxation frequency is lower in the psyllium system, followed by the flour system and the MC system. Power regressions of shifting factor versus strain rate show the highest power for the MC system.

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PO80

Dynamics of beer thin liquid filmsEmmanouil Chatzigiannakis, Alexandra Aliche, and Jan Vermant*Department of Materials, ETH Zürich, Zürich, Switzerland*

Thin liquid film (TLF) dynamics is considered to be the governing factor when it comes to foam stability. When two bubbles come into close proximity a TLF is usually formed between them, which gradually drains. The drainage process and, consecutively, the stability of TLFs has been found to depend heavily on the mechanical properties of the interface. For example, beer foam stability is believed to be enhanced by the formation of a rigid protein film at the CO₂/liquid interface that hinders Ostwald ripening and coalescence [1]. Although the addition of certain proteins during the brewing process is common industrial practice, the mechanism by which they act still remains unclear. The drainage of five different commercial beer foam TLFs was evaluated using newly developed variation of the thin film balance technique coupled with interferometry [2]. The influence that the surface tension, bulk and interfacial rheological properties have on TLF stability was assessed by pendant drop tensiometry, double-wall ring interfacial rheometry and bulk viscosity measurements. The surface tension and the viscosity of all five beers did not show large variations. However, their drainage behaviour differed significantly. Increased film stability, highly heterogeneous film thicknesses and lower thinning rates were observed for the beers of higher quality. Comparison between the experimental drainage curves and the predictions of the Reynolds model [3] indicates that the interfaces are highly stress-carrying. Furthermore, it was observed that the drainage time increases with the interfacial shear viscosity. Enhanced film stability was attributed to the formation of a stable viscoelastic layer, which greatly decelerates the drainage of the TLFs. More experiments are currently underway in order to determine the exact stabilization mechanism of beer TLFs.

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PO81

Viscoelastic properties of microfibrillated cellulose (MFC) produced from agricultural residue corn stoverJingyuan Xu¹, Wen-Ching Liu², and Veera M. Boddu¹¹NCAUR, ARS, USDA, Peoria, IL 61604, United States; ²University of Illinois, Peoria, IL, United States

The rheological properties of microfibrillated cellulose (MFC) produced from agricultural residue corn stover were investigated. The corn stover MFC gels exhibited concentration-dependent viscoelastic solid properties. Higher corn stover MFC concentrations resulted in stronger viscoelastic properties. The analysis for moduli of different concentrations and stress relaxation measurements indicated that the corn stover MFC gels were physical gels, meaning the cross-linkers between the molecules exhibited physical interactions. The non-linear steady shearing rheological properties studies implied that the corn stover MFC gels exhibited shear thinning behavior, which can be well fitted with the Power-Law Constitutive Equation. The function and behavior of the corn stover MFC gels suggest that this kind of starch-based biomaterial could be a potential candidate for applications in cosmetic gels and wound skin care materials.

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PO82

Physical aspects of the electro-osmotic flow and their effects on the transportation of DNA in lab-on-chip systemsPantelis Moschopoulos, Yannis Dimakopoulos, and John Tsamopoulos*Department of Chemical Engineering, University of Patras, Patra, Achaia 26225, Greece*

The carefully controlled flow of DNA samples, which are meant for extraction and amplification processes [1], is still an open problem for the industrial sector and a growing field of research. The flow due to an externally applied electric field is preferred in microsystems due to the benefits it provides, such as the fast and structure-preserving transportation. We model the mixed, electro-osmotic/pressure-driven flow in confined geometries of biofluids under the steady-state assumption. Our work is based on the formulation of Sousa et al. [2]. Here, we introduce a more general case by including a solvent contribution to the polymeric solution and by using a modified Poisson-Boltzmann [3] equation for the electric field. The influence of the pressure forces combined with the electric forces is analyzed in terms of the velocity field. The parametric study shows that the important parameters of those systems are the thickness of the electric double layer (ζ), and the viscosity ratio (β). We prove that the flow field is mainly affected by the charge density distribution near the wall rather by the intensity of the electric field or the wall potential. A case is studied, where the contribution of the electric field is negligible. Also, we present the range of parameters where this approximation is valid. A comparison is made with experimental data [4], which verify the existence of a depletion layer close to the wall. Also, we reduce the accurate but cumbersome two-phase model to a simpler single-phase model given by algebraic expressions. As a result, we get accurate result with little computational power.

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Wednesday 18:10 Foyer Sirene

PO83

Rheology can be hot: high temperature rheometryJoerg Laeuger*Anton Paar Germany, Ostfildern, Germany*

Rheometrical methods are well established for investigation on complex materials. An accurate temperature control is essential for correct results. However, standard heating accessories for commercial rheometers are limited to temperature of about 500°C or 600°C. Many industrial materials such as for example glass, ceramics, metals, and slags are still below their glass transition and their melting points at these temperatures. Existing devices for evaluating the rheological behavior of such materials at high temperatures are often limited to being either of a simple viscometer type or to individual designed self-made. In this paper two devices are being described which extend the temperature range for doing full rheological measurements beyond its current limit. First, a redesigned convection oven, which still fits into a standard commercial rheometer, allows measurements up to 1000°C in parallel-plate, concentric cylinder, and solid torsion geometries. With the later torsional DMTA investigations are possible. Second, a combination of a rheometer head with an external oven pushes the accessible temperature range up to more than 1700°C. In this device concentric cylinder geometries made of ceramics or platinum are used. Applications discussed in the paper range from glass, enamel, slags, aluminum alloys, basaltic melts, molten rocks, and molten salt and demonstrate the use of the described devices in performing high accurate and high precision rheological measurements at really high temperatures in many industrial and geological applications.

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PO84

Creation of weak gel from plant particlesCassandre Leverrier, Delphine Huc-Mathis, Abir Sadkaoui, Giana Almeida, and Gérard Cuvelier*UMR Ingénierie Procédés Aliments, AgroParisTech, INRA, Massy, France*

Weak gels of biopolymers are frequently used for food or cosmetic applications and their stabilisation property is particularly used in beverages containing pulps or other particles added in suspension. However, the trend of clean labelling tends to limit the use of added polymers in food. In this work, we point up how it is possible to functionalize fruit beverages only by processing and we highlight potentiality of plant particles weak gels. Fruit beverages containing fruit pulp and water were formulated and processed using several mechanical treatments (grinding and high pressure homogenisation). These mechanical treatments led to a decrease in particle sizes and modification of the rheological behaviour of the fruit beverages, passing them from liquid behaviour to weak gel behaviour. To characterize the network properties, the stress level at rupture and the mechanical recovery after shearing were evaluated. The behaviour of these gels under large strain was studied either in dynamic mode or under constant low shear rate

conditions. Above the yield stress, processed beverages have the ability to flow and to instantly restructure after flow. From a macroscopic point of view, the process used in this study allowed to stop sedimentation and to stabilised the fruit beverages without the addition of additives.

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PO85

Rheological investigations on the drying of polymer dispersions and paint films – A simple and reliable way to determine the open time

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Among the technical challenges which have arisen due to the switch from solvent to waterborne paints - driven by the regulatory push towards a more sustainable coatings industry - the control over the drying and film forming process of paint dispersions has been matter of intense investigation in recent years. Advanced analytical methods and imaging techniques have been used to gain insights into the mechanisms driving those processes and to identify factors which influence open time. Regardless sophisticated analysis, we still see the need for a simple and easily accessible method which allows for a quantitative differentiation of drying behaviour of aqueous paints and, moreover, on that will helps formulators to select the most favourable ingredients for specific products and applications. This is particularly relevant for the identification of additives for the prolongation of open time, which refers to the period of time remaining after paint application to make corrections without leaving visible defects in the film. This part of the painting process is still a challenging task due to the lack of an objective and stable method for its evaluation. A simple rheological method based on a novel measuring system attached to a highly precise air-bearing rheometer has been developed and will be presented which enables the investigation of the drying behaviour of aqueous paints. The detected change of torque over time is directly related to a change of film viscosity and allows therefore to detect the formation of a high viscous close-packed arrangement of particles as a characteristic transition during drying. The method has been successfully tested in the characterization in drying behaviour of four commercial polymer dispersions and also in the investigation of the effect of two additives on the drying process of the polymer dispersions. Furthermore, the method has been successfully used to evaluate the impact of additives on the drying of high and low pigment volume.

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PO86

Wall slip of highly filled powder injection moulding compounds

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Uneven distribution of solid particles contained in the feedstocks used in the process of powder injection molding (PIM) is observed in the close vicinity of the walls. A particle-free thin layer adjacent to the walls is formed by the binder only and is characterized by so-called wall slip. For its determination we used in our experiments capillary rheometers equipped with the dies of different entrance angles applied to four PIM feedstocks. Dominance of the binder component in a characterization of the wall-slip phenomenon was corroborated.

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PO87

Powder flowability study to optimize mixing and predict final product properties: A study on PVC formulations

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The rheology of granular flow has recently been a topic of interest for additive manufacturing, 3D printing and laser sintering applications where the polymer is directly processed in a powder form. In this work, we study the effect of impact modifier, filler type and level on the rheology of PVC compounds. In particular, the aggregation and demixing of CaCO₃ particles from the PVC matrix has been observed at certain CaCO₃ concentrations leading to reduced impact performance. Dynamic powder testing was performed on 25 different PVC compounds with a concentration of CaCO₃ in the range of 5 to 50%wt. The data showed a good correlation between powder flow properties (BFE, SI and FRI) and formulation ingredients (IM, CaCO₃, and TiO₂). Finally, the correlation between properties-structure and performance will be investigated.

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PO88

LAOS analysis of tyre rubber compounds: effect of the rubber chain-end functionalization on the nonlinear dynamic response

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The Large Amplitude Oscillatory Shear (LAOS) technique as a rheological characterization tool is nowadays one of the most appropriate and popular ways to evaluate the non-linear response of elastomers and their compounds; specifically, the technique is applied more and more frequently also to compounds for tyre industry. In this work, LAOS technique was applied on carbon black filled technical compounds, based on solution SBR with chain-end functionalization, synthesized in Ravenna Versalis pilot plant. The results, analyzed both by Fourier transform (behavior of harmonics) and visualization through Lissajous-Bowditch plot, were

used to discriminate the effect of functionalization on the final compound properties for tyre sector. Particularly it has emerged that functionalization causes a distortion of the stress vs strain cycle shape and reduces the energy dissipation (decrease of cycle area): in cured compounds even more than in uncured mixtures. These tests did not allow us to ascertain how functionalization influences the filler dispersion in the rubber, whereas the FFT harmonics behavior can reveal a possible effect on the rubber-filler interaction.

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PO89

Influence of elongational flow behavior of acrylate thickeners on their atomization with a high-speed rotary bell atomizer

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High-speed rotary bell atomization is a widely used application for coating of car bodies, since high coating quality is achieved at short process time. In this process, ligaments are formed at the bell edge, which disintegrate into droplets. Using shaping air stream droplets are directed to the target. In order to adjust a desired coating result and to prevent coating defects, it is necessary to understand the whole atomization process. Numerous studies investigated the influence of application parameters and shear viscosity on droplet size. Most studies are restricted to Newtonian fluids, although industrial paints are Non-Newtonian fluids. So, the effect of elastic and elongational flow properties of coating colors on atomization was not considered sufficiently. In this study a model system was formulated consisting of mixtures of different acrylate thickeners allowing for a variation of elongational flow behavior without changing shear flow properties. Steady shear viscosity and complex shear modulus $G^* = G' + iG''$ were obtained from rotational rheometry. Elongational flow resistance was characterized using Capillary Breakup Elongational Rheometry (CaBER). Droplet size distribution of the spray was determined using phase-Doppler-anemometry (PDA). Additionally, atomization was recorded using a high-speed camera allowing for a detailed analysis of ligament disintegration. We show, that increasing elongational flow resistance leads to an increase of ligament length. Droplet size shows no dependency on elongational viscosity. Decreasing rotational speed results in an increase of ligament length and droplet size, whereas volume flow rate hardly influences atomization properties.

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PO90

Material design of polycarbonate with high flowability

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The effect of the addition of low-molecular-weight polystyrene (L-PSt) on the flow curve of polycarbonate (PC) was evaluated using a capillary rheometer. It was found that the decrease in the melt viscosity by the addition of L-PSt was greater than that expected by the linear viscoelastic properties. Furthermore, this was prominent in the high shear rate region. Based on the detailed morphology characterization in the extruded strands, we confirmed that the enhanced flowability was provided by 1) flow-induced mixing and 2) segregation of L-PSt on the surface of the extrudates.

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PO91

Pressure drop analysis and time dependent flow rate of thermoplastic polymers during a MFI test

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Standard test methods for the melt flow rate of thermoplastic polymers through dies of specified length and diameter are available and largely used in industry as quality control tools (e.g. ASTM D1238-04 and ISO 1133-1). These methods prescribe precise temperature and load conditions. In addition one also finds clear instructions for the piston position in the barrel to be considered as the measurement is being made. These latter specifications are not minor details and have to do with intrinsic influence of the piston position on the MFI value measured. One thing that cannot be forgotten, when measuring the MFI, is that not only the resistance to flow of the capillary by itself is measured, but also a significant contribution by the reservoir comes into play as it is emptied during the course of the experiment. Keeping in mind that the MFI measurement is performed at constant load, as the reservoir empties the pressure applied at the entrance of the capillary will increase. The magnitude of this effect, which produces a time dependent flow rate leading to a kind of "marching MFI", depends on the weight chosen, on the geometry and on the particular dependence of the viscosity on the shear rate for the polymer at study. It is known that thermoplastic polymers exhibit a viscosity decrease when the rate of deformation is lowered (shear thinning). A realistic estimate of the pressure drop variation at the entrance of the capillary during the test has been done in this work using the Cross model and the results were compared with experimental data on polystyrene and polyethylene samples. The pressure drop analysis here proposed gives details of every pressure drop contribution involved during the MFI test and will hopefully clear this critical and often forgotten aspect of the MFI test.

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PO92

Raman-based analysis of phase-changing kinetic of anionic surfactant dissolutionAngela Capaccio¹, Giuseppe Pesce¹, Giulia Rusciano¹, Jaspreet Singh¹, Antonio Sasso¹, Ilaria Castaldo², Sergio Caserta², and Stefano Guido²¹Dipartimento di Fisica E. Pancini, Università Federico II, Napoli, Italy; ²Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

Sodium laurate ether sulfate is anionic detergent and surfactant that is economical and consumer benign in nature. The surfactant sodium lauryl ether sulfate (SLE3S) was dissolved in water at various concentrations (10 %-75 %). This dissolution range involves multi - phase dissolution process, i.e.: Lamellar, Cubic, Hexagonal and Micellar phases. These phases can be identified during the dissolution following the intensity of Raman bands concerning the C-Hn vibrations of the polymer bonds and O-H of water. Image scanning and time series provide information on the homogeneity of the samples and on the kinetic of the diffusion of water across the material. Before the addition of water, the C-Hn and O-H bands, at the analyzed concentrations, were investigated. In particular, the intensities variations and the shifts in the peaks of the various vibrational components of the tetrahedral hydrogen bond structure of water, sensitive to the environmental condition at nanometric scale, was analyzed in order to correlate these changings with the different phase state of the SLES3.

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PO93

Flow induced morphology in bacterial biofilmsFederica Recupido¹, Giuseppe Toscano², Rosarita Tate³, Maria Petala⁴, Sergio Caserta², Stefano Guido², and Thodoris D. Karapantsios¹¹Chemistry Department, Aristotle University of Thessaloniki, Montella, Avellino 83048, Italy; ²Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy; ³IGB-CNR, Napoli, Italy; ⁴Civil Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece

Biofilms are consortia of microorganisms attached to a surface, embedded in a self-produced matrix of polymeric substances. They have many implications and issues in different fields, including bioremediation, industrial biofouling, and medical implants contaminations. Therefore, the necessity to study their formation and morphology, is essential. In this work, *Pseudomonas fluorescens* biofilms were grown using different in vitro-set ups. Typically, bacterial cultures in vitro occur under unpredicted chaotic flow. In this project, a continuous flow cell apparatus was designed and developed, with the aim to form biofilms under controlled shear conditions. The effect of shear rate on biofilm morphology has been investigated. In particular, biofilm morphology was evaluated using confocal and environmental electron microscopy. Biofilm structural organization was quantified by image analysis. Biofilms have a morphologically complex structure. Surfaces are covered by microchannels and microcolonies of different size and thickness. Microstructure depends on the culture conditions. The role of the flow is thus to create a more uniform surface coating, in comparison to the ones, obtained using standard grown techniques, which are based on static or uncontrollable flow conditions. Moreover, increasing the shear rate, biofilms appear to be less dense and thinner, due to the sloughing off process induced by the flow.

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PO94

Red blood cell dynamics at high shear rates: a new look at blood shear-thinningLuca Lanotte¹ and Manouk Abkarian²¹Science et technologie du lait et de l'œuf, STLO, Institut National de la Recherche Agronomique, INRA, Rennes, Ille-et-Vilaine 35000, France; ²Centre de Biochimie Structurale de Montpellier, Montpellier, France

Blood viscosity decreases with shear stress, a property essential for an efficient perfusion of the vascular tree. Shear thinning is intimately related to the dynamics and mutual interactions of RBCs, the major component of blood. Because of the lack of knowledge about the behavior of RBCs under physiological conditions, the link between RBC dynamics and blood rheology remains unsettled. We performed experiments at viscosity, shear rates, and volume fractions typical of the microcirculatory flow, and our study reveals rich RBC dynamics that govern shear thinning. In contrast to the current paradigm, which assumes that RBCs align steadily around the flow direction while their membranes and cytoplasm circulate, we show that RBCs successively tumble, roll, deform into rolling stomatocytes, and, finally, adopt highly deformed polylobed shapes for increasing shear stresses, even for semidilute volume fractions of the microcirculation. Our results suggest that any pathological change in plasma composition, RBC cytosol viscosity, or membrane mechanical properties can affect the onset of these morphological transitions and should play a central role in pathological blood rheology and flow behavior.

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PO95

Constitutive modelling of human skinJibbe Soetens¹, Gerrit W. Peters², and Cees Oomens¹¹Biomedical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands; ²Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

Skin mechanics is important for various fields of research, e.g. ulcer etiology, the interaction between skin and devices such as shaving appliances and prosthetic liners. For this, prediction of mechanical response of skin is essential. From a mechanical point of view, skin should be considered as a highly dynamic and complex composite that has non-linear viscoelastic, anisotropic and heterogeneous properties. The aim of this work was to develop a constitutive material model that is based on experimental evidence and capable of capturing the complex mechanical behaviour of skin. We implemented the constitutive model in a finite element code as a fibre-reinforced matrix with an elastic fibrous component and an isotropic, non-linear viscoelastic matrix. The fibres only contribute in extension and provide anisotropic properties. Heterogeneity was included by gradually varying the stiffness over skin thickness. Parameter optimization with respect to the experimental results was performed using an iterative parameter estimation

method. Three intrinsically different experiments were performed on ex-vivo human skin: large amplitude oscillatory shear (LAOS) to determine non-linear viscoelastic properties of the matrix. Digital image correlation (DIC) on the cross-sectional area is used to assess heterogeneity. Biaxial tensile tests were performed to determine the fibre contribution and assess anisotropy. Finally, micro indentation experiments were performed to determine the contribution of volume change. The model showed to be able to describe the non-linear viscoelastic response to LAOS. The anisotropic response of human skin to biaxial tensile loading was described more accurate than the well-established Ogden model. The response to indentation is slightly overestimated with the current set of parameters. Overall, our constitutive model is capable of describing the complex mechanical behaviour of human skin under shear, biaxial tension and indentation with a single parameter set.

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PO96

Role of hydrodynamic forces in beating orientation of mammalian motile cilia

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Fluid flow generated by a ciliated epithelium is a fascinating example of collective behaviour in nature: thousands of microscale whip-like structures called motile cilia beat at the same frequency and in a coordinated fashion. This dynamics has been reported to have fundamental physiological roles in microorganisms and in many organs of vertebrates. In the airways, the coordinated beating of motile cilia generates a fluid flow that is able to push the mucus towards the pharynx and so protect the lungs from any inhaled contaminants. Airway cilia must be aligned along the longitudinal tissue axis to generate proper mucociliary clearance. The establishment of such directional motility happens during ciliogenesis, a process that spans from late embryonic to early postnatal days. The biological or mechanical cue that drives such orientation is still unknown. Our hypothesis is that hydrodynamic forces could be involved in the breaking of symmetry for cilia orientation during ciliogenesis. We developed a novel organ-on-chip where airway cells can be grown in vitro and exposed to shear stresses during ciliogenesis. Specifically we apply fluid flow prior to ciliogenesis to mimic mechanical stresses from prenatal fetal breathing and air flow to study postnatal stresses caused by breathing. We have preliminary data suggesting that these shear stresses during development are indeed important for cilia alignment and global coordination.

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PO97

Equine blood suspensions: the benefit of being a race horse

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Blood is a viscoelastic fluid, whereby the viscoelasticity is the result of red blood cell (RBC) aggregation at low shear rate, and RBC deformation at high shear rates. Thus, blood suspensions are shear-thinning. There are remarkable species-specific differences in blood rheology. In particular, equine blood suspensions are characterized by pronounced time-dependent effects due to high RBC aggregability. Horses dedicated for performance such as racing can be divided into sprint (Thoroughbreds) and endurance (Arabians) types. Due to the different requirements, it may be expected that distinct horse breeds show relevant phenotypic features, which are reflected by hemorheological properties. The apparent median Young's modulus of equine RBCs, analysed by force spectroscopy on single cells is more than doubled compared to man. However, their glycosylation pattern allows high adhesion in saline, and the electrophoretic mobility of horse RBCs is enhanced. We measured shear moduli of Thoroughbreds' whole blood at different hematocrit levels (30-60%), tested at 37°C. Data were compared to Warmblood horses. Both, G' and $|G^*|$ were decreased in Thoroughbreds at each hematocrit (HCT), except 60%. Although G' of Thoroughbreds blood was reduced between 30 and 50%, its dependency on HCT was pronounced. Whole blood viscosity (WBV) was measured in steady shear flow (1000 - 1 s⁻¹). At 30% HCT (resembling the native value), WBV was decreased in Thoroughbreds (2.67(2.66/2.69) mPa.s) at 100s-1 as compared to Warmbloods (3.57(3.30/450) mPa.s). Each mechanism that lowers blood viscosity should be a benefit for a racing horse. We conclude that Thoroughbred horses have an advantage over Warmblood horses due to the reduced WBV and due to the decreased elastic component of blood viscoelasticity.

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PO98

Bacteria dynamic and collective behaviour influences on the rheology: an experimental approach

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The motility and the transport of active microorganisms are subject to increasingly studies owing to their relevance in ecology, medicine or technological applications. Microorganisms such as bacteria, algae, sperm, etc. developed many locomotion strategies to perform swimming as well as flagella, cilia or body deformations. In absence of external forces, those low Reynolds swimmers are able to propel themselves by "stretching" or "contracting" the fluid along the self-propelled body axis and are respectively called "pusher" and "puller". In absence of external forces the motion, i.e. the orientation, of the swimmer is fully random. Interestingly, bacteria subjected to low shear rate tend to align with the flow. Thus the active contribution modifies the apparent viscosity of the suspension. Macroscopic studies have already been performed on active suspension but do not permit to visualize in-situ bacteria behaviour with the flow. To better understand the correlation between bacteria dynamic and the macroscopic rheology, we investigate experimentally the local rheology of an active suspension of *Escherichia coli* (pusher-type) in the dilute regime. The suspension flows through a rectangular cross-section microchannel by imposed pressure. (i) Using phase contrast technique, we image bacteria's motion and reorientation with the flow. (ii) Bacterial suspension is seeded with fluorescent beads. Using μ -PIV and μ -PTV techniques we measure the local velocity of the active fluid in the height of the capillary. It allows us to determine the local shear rate. The local rheology is then discussed in light of macroscopic experiments [1] and theoretical models [2]. Our experimental approach finally helps us to link bacteria trajectories and collective behaviour to the rheology.

[1] López, H. M. et al. (2015). Physical review letters, 115(2), 028301. [2] Takatori, S. C. & Brady, J. F. (2017). Physical review letters, 118(1), 018003.

Wednesday 18:10 Foyer Sirene

PO99

Non Newtonian models for CFD simulation of blood flow in cerebral aneurysms

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Most simulations of blood flow in cerebral arteries and aneurysms model blood as a Newtonian fluid, neglecting its shear-thinning behavior due to high shear rates [1]. Treatment with endovascular devices leads to much lower shear rates inside the aneurysm sack, thus non Newtonian models are recommended. We measured the viscosity of whole blood samples with several hematocrits at different temperatures and various shear rates using a double gap cylinder viscosimeter. The results were then used to determine the factors of Casson and Carreau-Yasuda models for blood [2] utilizing weighted non linear least square regression. Using CFD simulation we modeled a stented side wall aneurysm at a bend cerebral artery and calculated the velocity of the blood stream. The comparison of the results of the different models showed an overestimation of the effect of the flow diverting stent by the Newtonian model. Since the significance of the viscosity model is subject of discussion [3, 4] further investigations including patient specific data (in vivo images and viscosity measurements) are desirable.

[1] Cebal, J. R. et al. (2005). IEEE transactions on medical imaging, 24(4), 457-467. [2] Boyd, J. et al. (2007). Physics of Fluids, 19(9), 093103. [3] Evju, Ø. et al. (2013). Journal of biomechanics, 46(16), 2802-2808. [4] Morales, H. G. et al. (2013). Journal of biomechanics, 46(13), 2158-2164.

Wednesday 18:10 Foyer Sirene

PO100

A falling needle rheometer for the measurement of whole blood

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Whole blood viscosity is an intrinsic value of the blood vessel system and therefore strongly related to the regulation system inside the respective body where a sample is taken from. Researchers all over the world measure whole blood viscosity in a total artificial environment. The blood is withdrawn from the body flowing into vacuumed plastic tubes coated with an anticoagulant. Then the blood is measured in instruments which require an unsealing of the tubes and therefore bringing it in contact with the atmosphere. We developed a compact sized falling needle rheometer which is able to measure the blood viscosity almost immediately after collection. Blood was withdrawn with non-Coated Vacutainer tubes and measured within 30 seconds. The blood always remained inside the vacutainer vessel and the viscosity was measured via a falling needle with a distinctive mass. We also measured heparinized blood and blood with EDTA as an anticoagulant. Each measurement showed different results depending on the use of EDTA, Heparin and non-coagulated blood. Using different instruments and anticoagulation protocols leads us to the situation where we can reproduce a single experiment but we do not know if the measured viscosity equates the whole blood viscosity inside the mammal body. The falling needle rheometer enables us to measure the viscosity of whole blood leaving the sample as natural as possible

Wednesday 18:10 Foyer Sirene

PO101

The Enhancement of Mixing Efficiency of a Tee Channel by Ring Shaped Baffles

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The mixing in the passive microfluidic system is limited due to the laminar flow nature of microfluidics. To enhance the mixing efficiency of a tee channel, ring shape baffles were added in a tee channel to enhance mixing efficiency. The broken ring shape baffles were fabricated by SU8 photoresist via lithography and were embedded into the tee channel made of PDMS. The solution of DI water with methyl blue is mixed with ethanol and injected into this mixing chip by different flow rate. The flow mixing efficiency is estimated by taking the images of the flow pattern via a CCD camera and was analyzed with image analysis software. The numerical simulations are carried out by commercial software Comsol to investigate the multi-physics of flow field and the concentration field. In general, the experimental result is in good agreement with the concentration simulation. The effects of flow speed, the number of baffle, the orientation of baffles and the configuration of the baffle are investigated. The results show the higher the flow speed, the lower the mixing efficiency. This is due to the passive mixing is dominated by diffusion and the high flow speed does not have enough time for diffusion to react and is adverse for mixing. The increase of baffle number enhances the mixing efficiency which is the direct results of more flow stretching. The optimal mixing efficiency is 60 degree; however, it also has the highest pressure drop. If both the mixing efficiency and pressure drop is considered, then 45 degree is better. From mixing perspective, the optimal baffle configuration is the opening distance 10^{-4} um and the orientation 60 degree. The mixing enhancement mechanism is due to the increase of the velocity along the diffusion direction. Meanwhile, the mixing efficiency is increased if the placement of the baffle is against the wall. It is shown that the embedding of ring shaped baffles increases the mixing efficiency with proper orientation, opening distance and placement position.

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PO102

Numerical simulation of clogging in microchannelsMarco Trofa, Gaetano D'Avino, Giovanna Tomaiuolo, Francesco Greco, Pier Luca Maffettone, and Stefano Guido*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy*

One of the critical issues encountered when processing particle suspensions in microfluidics is clogging, which is primarily due to adhesion of particles to form clusters, and to the interaction of such clusters with the wall. Although these phenomena have been thoroughly studied, the complete mechanism of clogging is far from being fully understood. It has been shown that, in the early stage of the clogging process, a small number of clusters form at the channel wall, with negligible interaction among them, which simultaneously and independently grow in size through recruitment of individual particles from the suspension flow [1, 2]. In this work, we employ Computational Fluid Dynamics (CFD) simulations combined with Discrete Element Method (DEM) to study the initial growth of a cluster at the wall of a micro slit. We consider a suspension of 'soft' micro particles in a Newtonian liquid, with a simple model to describe particle-particle adhesion. Cluster growth is quantified in terms of projected area onto the slit wall, as this quantity can be readily measurable in experiments through optical microscopy. Effects of particle dimension, volume fraction, fluid flow, and adhesion intensity on the cluster growth rate are investigated. A reasonable agreement with experimental data available in literature is found.

[1] Gudipaty, T. et al. (2011). *Microfluidics and nanofluidics*, 10(3), 661-669. [2] Stamm, M. T. et al. (2011). *Microfluidics and nanofluidics*, 11(4), 395.

Wednesday 18:10 Foyer Sirene

PO103

Parametric study for the optimal design of pressure taps in microchannelsTomás Rodrigues Pinto and Laura Campo-Deaño*Departamento de Engenharia Mecânica, Faculdade de Engenharia da Universidade do Porto, Porto, Porto 4200-465, Portugal*

The recent advances in microfabrication techniques allowed the use of microfluidics for characterizing the complex flow dynamics around different microbot prototypes to be used in biomedicine [1]. However, the complete fluid flow characterization must include the determination of the pressure drop induced by the presence of the prototype in order to analyze the dynamic efficiency of these devices, which is a challenging task. Therefore, the final aim of this work is to assess the dynamic efficiency of microbots in complex fluid flows analogue to human blood flows. For that end, the assessment of the pressure drop originated by the presence of the prototypes is essential. The specific objective of this research is the study of the influence of different shape parameters in the design of the pressure taps in microchannels. Polydimethylsiloxane (PDMS) microchannels were fabricated with different 2D microbot prototypes. Different variables were considered in the design of the taps and the secondary microchannels connecting the taps: width of the secondary channel (w), radius of curvature of the tap (R), angle between the tap and the secondary channel (α) and length of the secondary channel (L). Pressure drop measurements were carried out with different combinations of these variables in order to determine the optimal design.

[1] Martínez-Aranda, S. et al. (2016). *Soft matter*, 12(8), 2334-2347.

Wednesday 18:10 Foyer Sirene

PO104

Axisymmetric creeping flow around particles in viscoplastic fluidsEmad Chaparian and Ian A. Frigaard*¹Mechanical Engineering, University of British Columbia, Vancouver, Canada*

From the mobility formulation of particulate flows, we know that a critical resistive force must be overcome in order for the particle to move. This translates geometrically to a critical envelope around the particle in the limit of zero flow that contains both the particle and encapsulated unyielded fluid. Such unyielded envelopes and critical yield numbers are becoming well understood for single (2D) particles (Chaparian and Frigaard, JFM, 2017 & Chaparian and Frigaard, JNNFM, 2017). Means of calculating critical yield number in 2D are well-known numerical algorithms for viscoplastic fluids (augmented Lagrangian algorithms) and also the method of characteristics in perfect-plasticity. Here we investigate the axisymmetric creeping flow around particles in viscoplastic fluids since it is of more interest practically. It mainly falls into three geometries: ellipsoid, cylinders, and cones. We will address the critical yield numbers or equivalently plastic drag coefficients in the yield limit for these classes of shapes for wide range of aspect ratios. We mostly here use numerical approaches since the equations of axisymmetric perfect-plasticity flows (Levy-Mises equations) are not hyperbolic anymore and so method of characteristics is not of interest in this condition due to presence of Hoop stress.

Wednesday 18:10 Foyer Sirene

PO105

Rheo-PTV analysis of yield stress fluidsAli Pourzahedi¹, Masoud Daneshi², and Dana Grecov³*¹Mechanical Engineering, University of British Columbia, Vancouver, British Columbia V6H 3Z3, Canada;**²Department of Chemical and Biological Engineering, University of British Columbia, Vancouver, Canada;**³Mechanical Engineering, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada*

A novel microfluidic device has been developed for measuring the rheological characteristics of complex fluids. Having the capability to be integrated with flow visualization techniques, microfluidic rheometers are ideal while dealing with yield stress fluids. They also allow to visualize the complex behavior of yield stress fluids through a wide ranges of shear rate. Thus, any effect due to the flow configuration (e.g. wall slip and fluid fraction) on the rheological behavior of the materials could be detected and visualized. The objective of this work is to characterize the behavior of the yield stress fluids at stresses lower than the yield stress. Carbopol, as a yield stress fluid, was used as the working fluid to investigate its time-dependent behavior and flow configuration with respect

to its rheological properties. Optical Coherence Tomography (OCT) was used to visualize the flow of tracing particles and Particle Tracking Velocimetry (PTV) was further used to find the flow profiles (known as OCT-PTV technique). Stress vs. shear rate for stresses below yield stress was studied. It was shown that pressure drop changes linearly with the flow rate where wall stress becomes less than the yield stress. Thus, this confirms the development of an apparent slip layer of water near the wall (Meeker et. al, Journal of Rheology, 2004). Presence of the slip-yield stress was also investigated for different concentrations of carbopol.

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PO106

Effect of rising motion of spherical bodies on structured fluids with yield stress

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In this work, the analysis of the physical stability of a structured detergent containing air bubbles has been performed on a simplified model fluid used for washing machines. The system is a suspension of hydrogenated castor oil colloidal fibers in a surfactant micellar solution. The fiber network confers to the fluid a viscoelastic behavior, with a well-defined yield stress, which increases with increasing fiber concentration. The main responsible of this instability is the action of an external force, i.e. the load applied by air bubbles which sometimes are found into finished structured detergents due to processing conditions. The network can be subjected to a clear phase separation, with the matrix without fibers standing on the bottom of the fluid volume, whereas a more concentrated system is forming towards the free surface. We studied various samples, which differ from each other for aeration level and fiber concentration. The rheological behavior and the microstructure of these fluids have been rheologically characterized. To try to model the real system, we also replaced the air bubbles with hollow glass microspheres. The motion of a spherical single body as well as the cooperative effect of the particle ensembles have been analyzed by a home-made time lapse photography technique in a way to study the dynamics of the spherical bodies and to verify the possibility of a microstructure collapse in the presence of many spheres. The experiments last as long as several weeks. The rising motion of the single sphere and the edge split during phase separation have been monitored by changing various parameters such as temperature, aeration content and fluid yield stress. The results are novel for the peculiarity of the system and for the wide range of aspects used to study the phenomenon. The results could have important implications in the fabric and personal care detergency, a technological area where many fluids have composition and show rheological properties similar to those considered in the current work.

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PO107

Dynamics of viscoelastic migration in confined Poiseuille flows

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Flows of particles in viscoelastic liquids are involved in geological, biological or industrial applications. Recently, numerous studies have revealed that the particle motion is affected by fluid elasticity [1, 2]. In particular, transversal migration of particles, i.e. a motion across streamlines, is reported due to a gradient of shear rate around particles. The fine comprehension of this phenomena should allow us to manipulate and control the particle motion in confined flows [3]. Indeed, viscoelastic migration is very promising for sorting applications, since the net normal force acting on the particle scales as a^3 , where a is the particle size. In this project, we aim at better understanding and describing in details the phenomena involved. To this goal, we measure the transversal particle migration kinetics in confined Poiseuille flows of a dilute polymer solution. For example, in case of an aqueous solution with a 10 % mass fraction of polyacrylamide (Mn=150000, Sigma Aldrich), and with diluted 10 μm polystyrene beads (<0.1% vol), we observed that all the beads are contained in the central 10 μm layer of a 50 μm deep channel after flowing 4 cm at 1 mm/s. Then, our goal is to correlate this kinetics with direct measurements of rheological properties (e.g. viscosity, relaxation time and normal forces) The fluid being weakly elastic, measurements with standard rotational rheometer are not efficient. Thus, we are using the slow retraction method of CaBER experiment [4] to measure fluid relaxation time smaller than 1 ms.

[1] Leshansky, A. M. et al. (2007). Physical review letters, 98(23), 234501. [2] D'avino, G. & Maffettone, P. L. (2015). Journal of Non-Newtonian Fluid Mechanics, 215, 80-104. [3] Yuan, D. et al. (2018). Lab on a Chip, 18, 551-567. [4] Campo-Deano, L. & Clasen, C. (2010). Journal of Non-Newtonian Fluid Mechanics, 165(23-24), 1688-1699.

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Wednesday 18:10 Foyer Sirene

PO108

Viscoelastic alignment, separation and ordering of particles in straight microfluidic channels

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Controlling the fate of particles and cells in microfluidic devices is critical in many biomedical applications, such as particle and cell alignment and separation. Several techniques have been proposed to manipulate the trajectories of particles suspended in a moving fluid. Many of them rely on the use of external forces generated, for instance, by electric, magnetic, or acoustic fields. The resulting platforms are, however, sometimes bulky, and require fine-tuning of the field strength. We show that suspending viscoelastic polymer solutions can be employed for alignment, separation and ordering of particles in simple straight square-shaped microchannels, without any external field. The height of the square-shaped microchannel is kept constant at 100 μm . Polystyrene particles with diameters ranging from 6 -20 μm are suspended in several viscoelastic solutions that are either shear thinning or purely elastic with constant viscosities. Aqueous solutions of polyvinylpyrrolidone (PVP) 8 wt%, PolyEthylene Oxide (PEO) 0.1 wt% and 0.8 wt% are purely elastic with near constant-viscosities. Hyaluronic acid (HA) 0.8 wt% and 1 wt% exhibit shear-thinning behavior. Particles suspended in purely elastic fluids (PVP 8 wt%, PEO 0.1 wt% and PEO 0.8 wt%) migrate towards the channel centerline regardless

of their initial positions. In a shear-thinning liquid (HA 0.8 wt%), particle positions over the channel cross-section can be shifted "from the edge to the center" when increasing the particle diameter while keeping the channel dimensions fixed. In the same shear-thinning liquid, separation of 10 and 20 μm particles can be further achieved in a straight microchannel with an abrupt expansion. Finally, we show that particles suspended in HA 1 wt% can be equally spaced, i.e. ordered, in a simple straight channel.

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PO109

Viscoelastic flow around microfluidic cylinders with high aspect ratios and low blockage ratios

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We employ a state-of-the-art microfabrication technique (selective laser-induced etching, SLE) to produce microfluidic cylinder geometries that explore new geometrical regimes. Using SLE, microchannels are fabricated in monolithic glass substrate with heights $h = 2\text{ mm}$ and widths $w = 0.4\text{ mm}$ (aspect ratio $\alpha = h/w = 5$). The cylinders have radii $r = 0.02\text{ mm}$ and thus provide low blockage ratios $\beta = 2r/w = 0.1$. The channels contain either a single cylinder, or a pair of cylinders aligned on the flow axis (separated by a distance $50r$). Compared with cylinder geometries fabricated in PDMS by soft lithography (which typically have $\alpha \ll 1$ and $\beta = 0.5$ [1]), these rigid glass devices provide a quasi-2D flow through the channel depth and more clearly reveal the effects of the extensional wake regions at the leading and trailing stagnation points. We use our novel geometries to study the flow of a well-characterized viscoelastic dilute polymer solution at a high elasticity number $El \sim 2400$. For a single cylinder, as we increase the Weissenberg number (Wi) of the flow (for Reynolds numbers $Re \ll 1$), birefringence measurements reveal the stretching of polymer upstream of the cylinder and the development of an extremely long elastic downstream wake extending $>300r$ behind the cylinder. This is accompanied by severe modification of the flow field compared with the Newtonian case. We also observe the onset of purely-elastic instabilities upstream of the cylinder. In the geometry containing two cylinders, as Wi is increased and the wake of the upstream cylinder grows longer, the downstream cylinder eventually becomes encapsulated by it, and is effectively obviated from the flow field. The results have significance for cyclic flows of dilute polymer solutions, such as in porous media.

[1] Zhao, Y. et al. (2016). *Soft Matter*, 12(42), 8666-8681.

Wednesday 18:10 Foyer Sirene

PO110

Predictions for thixotropic viscoelastic and viscoelastoplastic fluids in flow past a sphere

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In this modelling study, a quantitative evaluation is performed to address the impact of time-dependent properties of thixotropic viscoelastoplastic micellar fluids on flow past a sphere. Such analysis is based on flow-structure, drag coefficients and stress fields. A wide range of solute-concentration is considered, where dilute micellar solutions (solvent-fraction of 90%) and highly-concentrated solutions (solvent-fraction of 0.1%) bound the concentration range analysed. As such, this study covers two flow-regimes: the viscoelastic regime (low solute-concentration), and the plastic regime (highly-concentrated gelled materials). A flow-rate increase protocol is utilised, covering low flow-rates (plastic-like phenomena), intermediate flow-rates (interplay of plastic and viscoelastic features), and high flow-rates (dominant viscoelastic features). The time-dependent equations of state used to characterise such complex fluid flows comprise the newly-proposed wormlike-micellar-based BMP+ τ_p model and a variant of the oil-flow-based De Souza model. The BMP+ τ_p model stands as a versatile model which predicts such rheological features as extreme shear-thinning and strain-hardening/softening; whilst also being capable of supporting plasticity and shear-banding through variation in solute-concentration. In addition, this particular BMP+ τ_p model-variant has the additional beneficial rheological properties of bounded extensional viscosity and non-linear first normal-stress difference in shear at high deformation-rates. The numerical algorithm employed is that based on a well-founded hybrid finite element - finite volume scheme for the spatial discretisation of the flow domain, embedded in a pressure-correction fractional-staged time-stepping procedure. This algorithm is imbued with the novel ABS-f and VGR corrections, which act upon thermodynamical consistency of the constitutive equation and well-posedness of the initial-value problem, respectively.

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PO111

Three-dimensional natural convection of shear-thinning fluids in a rectangular enclosure

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Three-dimensional steady-state simulations of Rayleigh-Bénard convection in a rectangular cavity have been conducted. The enclosure is considered to be filled with shear-thinning Non-Newtonian fluid containing different concentration of a xanthan gum (XG) in water ranging from 0.1% to 0.2%. The enclosure is a parallelepiped shape with 50mm length, 20mm high and 10mm depth. The bottom wall is maintained at constant heat flux and the top wall at constant temperature while the other walls are insulated. The nonlinear equations subject to these boundary conditions are solved using a finite-volume solver. A parametric study is performed and the effects of the Rayleigh number and XG concentration on the flow pattern and heat transfer characteristics inside the cavity are investigated. The structure of fluid flow and temperature field are given by streamlines and isotherms for different Rayleigh numbers and different shear-thinning fluids. The results show that multiple solutions exist mainly for the most viscous fluid (0.2% X-G) depending on the fluid structure and temperature field. For the case of two counter-rotating cells there exists two stable solutions. One given by a central plume, where the two convection cells are going up in the center of the cavity. The second solution is wall plumes and the convection cells rotate in opposite senses. A third solution is a combination of two wall plumes convecting fluid to the center of the cavity and in total there are four cells, two big rolls in the center and two small rolls near the walls. Heat

transfer given by Nusselt number (Nu) shows that wall plumes (down wards recirculation) is higher than other configurations, and Nu increases with an increase of xanthan gum concentration. Supporting experimental measurements will be presented.

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PO112

Instability of Saffman-Taylor for yield stress fluids in Hele Shaw cell

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Our interest is in the instability of Saffman-Taylor for yield stress fluids in porous medium. One studies here the possible viscous digitation of circular samples moved radially in a Hele Shaw cell. This flow is the analogue (two-dimensional) of a flow in a porous medium [1, 2]. For a Newtonian fluid the instability occurs beyond some velocity of the interface. Below it the interface remains circular. By injecting air at controlled flow rate in the center of the cell initially filled with a yield stress fluids, the air-liquid interface moves towards outside. Two modes of flow are however then observed: beyond a critical velocity the air penetrates in the form of fingers through the material; the fluid leaves traces on the walls, indicating that in these zones it is sheared; this first mode resembles the instability of Saffman-Taylor for yield stress fluids [3]. Below this critical velocity the air region grows bigger regularly but the interface is still unstable, deformations resembling fractures are observed at various points of the interface. Moreover in this second mode the fluid does not leave tracks on the walls, indicating that it slips, except around the points of fracture. This new phenomenon resembles a phenomenon of fracture in a solid material (cf. eg.g. Griffiths analysis). In fact this mode is particular: taking into account the slip to the walls one should obtain an elongation 2D material; the fact that we systematically get such fractures, whatever the speed, suggests that the elongation 2D of a yield stress fluids is unstable.

[1] Homsy, G. M. (1987). Annual review of fluid mechanics, 19(1), 271-311. [2] Saffman, P. G. & Taylor, G. I. (1958). Proceedings of the Royal Society A, 245, 312-329. [3] Coussot, P. (1999). Journal of Fluid Mechanics, 380, 363-376.

Wednesday 18:10 Foyer Sirene

PO113

Squeeze flow of Bingham plastic with stick-slip at the wall

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We develop an asymptotic solution for the axisymmetric squeeze flow of a viscoplastic medium both for no-slip and slip yield boundary condition at the wall. The standard lubrication-style expansions of the problem with the no-slip condition predict a plug speed which varies slowly in the principal flow direction. Our solution shows that this region is a pseudo-plug region in which the leading order equation predicts a plug, but really it is weakly yielded at a higher order. We follow the asymptotic technique suggested earlier by Balmforth and Craster (1999) and Frigaard and Ryan (2004). This method involves no relaxation of the exact Bingham model. We have extended the asymptotic analysis to the case of a threshold stick-slip boundary condition. Just as in the case of no-slip condition, we provide expressions for velocity, stress, pressure and squeeze force. Depending on the ratio of two dimensionless parameters partial slip (stick-slip) or full slip at the wall (slip) are possible. We also provide comparison between analytical solution and numerical computations using the augmented Lagrangian method. The analytical solution is in very a good agreement with the numerical results.

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PO114

Application of machine learning to viscoplastic flow modeling

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We present a method to construct reduced-order models for duct flows of Bingham media. Our method is based on proper orthogonal decomposition (POD) to find a low-dimensional approximation to the velocity and artificial neural network to approximate the coefficients of a given solution in the constructed POD basis. We use well-established augmented Lagrangian method and finite-element discretization in the "offline" stage. We show that the resulting approximation has a reasonable accuracy, but the evaluation of the approximate solution several orders of magnitude times faster. We also provide results for non-homogeneous yield stress limit.

Wednesday 18:10 Foyer Sirene

PO115

Symmetry and steadiness aspects of purely-elastic instabilities in a cross-slot flow

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The presence of long-chain polymer molecules in a fluid can lead to flow instabilities and nonlinear behaviour at vanishingly low Reynolds number, a phenomenon that can not occur in Newtonian fluid flows. Such instabilities arise from the development of polymeric elastic stresses in the fluid and have been characterised in geometries with stagnation points beforehand, like the *cross-slot* arrangement. It consists of two perpendicular and bisecting channels with two opposing inlets and outlets, generating an elongational flow; this setup is one of the most representative cases of geometries with stagnation points, with great potential for mixing processes. Improving understanding and characterisation of flow phenomena in this geometry is thus fundamental to develop such fluidic devices. In this work, a numerical analysis is performed for the flow of viscoelastic Oldroyd-B fluids, by means of a finite-volume based open-source solver. We explore the capabilities of the solver, by ranging from moderate to high elasticity levels and delimitating the zones of symmetry and steadiness of the cross-slot flow, for multiple solvent viscosity ratios. By doing that, we are able to detect the two notable purely-elastic instabilities firstly reported by Arratia *et al.* (*Phys. Rev. Lett.*, 2006). The stability and steadiness boundaries for this cross-slot flow are investigated in the breadth of relevant parameters (Reynolds number, Deborah number and solvent viscosity ratio). A representative diagram is conceived using the ensemble of results, whose details will be explored in the present work.

Wednesday 18:10 Foyer Sirene

PO116

Interfacial stresses in miscible fluids: an insight from fluid dynamic instabilitiesDomenico Truzzolillo¹, Giovanni Savorana¹, Luca Lanotte², Manouk Abkarian³, and Luca Cipelletti¹¹*Laboratoire Charles Coulomb, Montpellier F-34095, France;* ²*Science et technologie du lait et de l'œuf, STLO, Institut National de la Recherche Agronomique, INRA, Rennes, Ille-et-Vilaine 35000, France;* ³*Centre de Biochimie Structurale de Montpellier, Montpellier, France*

Interfacial tension between immiscible phases is a well-known phenomenon, which manifests itself in everyday life, from the shape of droplets and foam bubbles to the capillary rise of sap in plants or the locomotion of insects on a water surface. More than a century ago, Korteweg [1] generalized this notion by arguing that stresses at the interface between two miscible fluids act transiently as an effective, nonequilibrium interfacial tension, before homogenization is eventually reached. In spite of its relevance in fields as diverse as geosciences, polymer physics, multiphase flows, and fluid removal, experiments and theoretical works on the interfacial tension of miscible systems are still scarce, and mostly restricted to molecular fluids. This leaves crucial questions unanswered, concerning the very existence of the effective interfacial tension, its stabilizing or destabilizing character, and its dependence on the fluid's composition and concentration gradients. To gain new insights into this fundamental issue we exploit hydrodynamic instabilities to deform interfaces between miscible fluids in different configurations (Hele-Shaw and Poiseuille flows) and relate the onset or the absence of flow instabilities, together with their features, to the existence of a stabilizing tension. We present an extensive set of measurements on miscible complex, molecular and biological fluids that demonstrate in some cases the existence and the stabilizing character of this effective interfacial tension, unveil new regimes beyond Korteweg's predictions [2], and quantify its dependence on the nature of the fluids and the composition gradient at the interface.

[1] Korteweg, D. J. (1901). Arch. Neerland. Sci. Exactes Naturelles 6, 1. [2] Truzzolillo, D. et al. (2016). Physical Review X, 6(4), 041057.

Wednesday 18:10 Foyer Sirene

PO117

The effect of nozzle geometry on drop dispensing of a viscoelastic fluid in viscous outer mediumsClaudiu Patrascu and Corneliu Balan*REOROM Laboratory, University Politehnica, Bucharest 060042, Romania*

Break-up of liquid jets and associated drop dispensing from a circular nozzle is a subject that received great attention in the past studies. Controlling and predicting the break-up phenomenon is of great importance in a number of practical applications, such as dosing consumer products and ink-jet printing technology. An external viscous liquid medium is used when the jets dynamics need to be slowed down. Also, in the case of an immersed jet, the drop generation time increases, offering the possibility of performing studies in a reduced-gravity environment. Despite these advantages, the study of a two-fluids dynamics is more complicated since the number of characteristic parameters doubles and the frontier between regimes is a priori unknown. This paper tackles the task of investigating the dynamics of two-fluid systems, at low Weissenberg and Bond numbers. In this paper we study the effect of nozzle geometry on drop generation in both dripping and jetting regimes. Using a 3D printing machine, four types of nozzles with different cross-sections were constructed: circular, elliptical, hexagonal and a square type of geometry, all having the same cross-sectional area and similar hydraulic radius. We considered purely viscous water-glycerin mixtures and viscoelastic polyacrylamide solutions, dispensed in an immiscible liquid oil. The effect of nozzle geometry on the frequency of drop generation in the dripping regime and the differences in filament thinning brought by a change in the shape of the cross-section are pursued. A simple theoretical model for the frequency of drop generation is used by considering that at drop detachment the reduced force of gravity is balanced by interfacial tension and elastic stresses (for the viscoelastic case). The capillary instability of a liquid jet is a well-documented phenomenon, studied for circular and elliptical nozzles. In this paper we look at two more geometries and emphasize their effects on the stability of the liquid jet column.

Wednesday 18:10 Foyer Sirene

PO118

Onset of air invasion into an elastoviscoplastic fluidMarjan Zare¹, Andrew Dworschak², and Ian A. Frigaard¹¹*Mechanical Engineering, University of British Columbia, Vancouver, Canada;* ²*Engineering Physics, University of British Columbia, Vancouver, BC V6T 1Z1, Canada*

We study air invasion driven by a source-point of pressure to a stationary elastoviscoplastic fluid. Onset of flow is observed by a bubble arising from an orifice placed at the bottom of a column of fluid. For Newtonian fluids, once the applied normal pressure balances the hydrostatic pressure and surface tension, the first bubble emerges. In contrast, the yield stress fluids may remain stationary under the same pressures. We identify the critical pressure at which flow onset takes place and determine the main parameters controlling this pressure. In addition, the effect of governing parameters of the problem including the rheology of the fluid and height of the fluid column on the critical pressure are examined. In comparison with the invasion pressures obtained for other fluids, Zare, M, et al (2016), it is shown that the surface tension plays a dominant role in the case of gas invasion into the column of the yield stress fluid. In addition, our results suggest that the invasion pressure is not strongly dependent on the height of the column of yield stress fluid. It can be attributed to the fact that the yielding region surrounding the bubble is localized. The bubble's formation pressure is found to be enough for bubble's pinch-off, since buoyancy is then driving the ensuing bubbles. The kinematic of bubbles rising through the column of fluid are also studied. The bubbles are cusped shaped and their shape and migration path may vary to facilitate their movement along the yield stress fluid column. It is demonstrated that the main dynamic features of bubbles, when they reach to the steady state, are different from those obtained in the solutions of steady bubbles. The fluid's structure after first invasion is destructed. The results obtained by repeating the test with the same fluid sheds light on the amount of this destruction.

Wednesday 18:10 Foyer Sirene

PO119

Instabilities in buoyant miscible displacement flow of shear-thinning fluids in an inclined duct

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We study displacement flow of two miscible fluids with density and viscosity contrast in an inclined pipe. Our focus is mainly on displacements where transverse mixing is not significant and thus a two-layer, stratified flow develops. The experiments are conducted in a long pipe, covering a wide range of flow-rates, inclination angles and viscosity ratios. Density difference is achieved by adding Glycerol to water. To set a viscosity contrast different concentrations of Xanthan gum is added to water to get weakly shear-thinning solutions. At each inclination angle flow rate and viscosity ratio are varied and the resulting flow regimes are identified. Displacing a shear-thinning fluid results in very unstable two-layer displacements. The instabilities grow as dispersive waves at the interface or unique instabilities growing at the thin layers of the fluid overrun by the displacing fluid. A number of numerical simulations are also completed to get a better insight into the flow structure and shear-thinning effects. Numerical simulations are completed using OpenFOAM in both pipe and channel geometries and are compared against the experiments.

Wednesday 18:10 Foyer Sirene

PO120

Nonlinear effects in mesoscopic theory of polymeric fluids flow at their large periodic deformationNadezdha Cherpakova¹, Jean-Charles Naud², and Grigory Pyshnograï³¹*Mathematics, Altai State Pedagogical University, Barnaul, Russia;* ²*Alkante-Bretagne, Rennes, France;*³*Mathematics and Information Technology, Altai State University, Barnaul, Russia*

Many materials with complex structures, including polymers, foams, gels, gelatins, etc., exhibit nonlinear viscoelastic properties, such as shear oscillations with large amplitude. At the same characteristics of the microstructure determine when and how such non-linearity may occur. Based on multimode Vinogradov and Pokrovskii rheological model, were carried out numerical calculations, imposing the shear oscillations with large amplitude on the flow of polymeric liquids. The results of the study of nonlinear viscoelastic properties are interpreted by plotting the Lissajous figures. In the study model was able to confirm the increase in the non-linearity of the response of the sample by increasing the amplitude of the oscillation frequency. It is shown that when the parameters of the model will be able to achieve change in the nature of the nonlinear response. These results allow the character of nonlinearity - pseudoplasticity, curing or softening of the environment depending on the magnitude of the shear strain.

Wednesday 18:10 Foyer Sirene

PO121

Temperature impact on the hydrodynamic characteristics of the polymer melts flows in the converging plane-parallel channelsAlexander Kuznetsov¹, Konstantin Koshelev², Ivan Pyshnograï³, and Grigory Pyshnograï⁴¹*Altai State University, Barnaul, Russia;* ²*Institute for Water and Environmental Problems SB RAS, Barnaul, Russia;* ³*Mathematics, Altai State Technical University, Barnaul, Russia;* ⁴*Mathematics and**Information Technology, Altai State University, Barnaul, Russia*

In work impact of polymeric melt s temperature on the sizes and intensity of the vortex area arising in case of a flow on an entrance to the slot-hole channel is considered. Mathematical description of a three-dimensional flow of melt in the converging channel is realized on the base of the modified Vinogradov and Pokrovskii rheological model generalized for accounting of non-monotonic behavior of gradient dependence of elongation viscosity and with Newtonian law for residual viscosity is used. Temperature dependence of initial shear viscosity of polymeric melt has the Arrhenius appearance. Initial relaxation time was estimated as by comparison with experimental data for gradient dependence of stationary viscosity in case of uniaxial elongation, and on the basis of molecular and kinetic approach. Sticking conditions for velocity on a wall have been used. Discrete analogs of system of the equations of dynamics of polymeric fluid were by method of control volume with separation on physical processes. In case of implementation of numerical algorithm the possibility of application of parallel calculations technology based on graphical processors was considered. In numerical experiments returnable courses of polymeric melt before an entrance to narrow part of the canal are found and it is shown that dependence of the vortex sizes and intensity on temperature of melt has non-monotonic character and passes through a maximum. It is also shown that polymeric flow before an entrance to the slot-hole channel has significantly three-dimensional character, the sizes of the vortex area calculated in the sections which are carried out at various distances from an axis of the channel in the beginning increase in case of approach to a firm wall, and then decrease. All features noted in calculations are observed also in real experiments on branched polyethylene of low density melts.

Wednesday 18:10 Foyer Sirene

PO122

Rheological model for polymeric fluids flows in square cross-section channel with slipping phenomenaIvan Pyshnograï¹, Grigory Pyshnograï², and Haider Al Joda³¹*Mathematics, Altai State Technical University, Barnaul, Russia;* ²*Mathematics and Information Technology, Altai State University, Barnaul, Russia;* ³*Department of Petroleum, University of Karbala, Karbala, Iraq*

Many fluid systems (polymeric and bio-polymeric materials including) reveal the anomaly of slipping often near the solid surface. The presence of such a wall effect leads to a violation of the hypothesis on attachment and the need to specify appropriate boundary conditions. This anomalous behavior of materials in a plastic state (slurry, grease, fluids and polymer melts) at solid surfaces requires a comprehensive study of both rheological properties and calculating the flow parameters and characteristics of the processing equipment. In the first place, there are rather complex problems of determining the rheological characteristics of the material results according to the viscometric studies. The next stage is associated with specific problems on the motion of fluids which exhibit abnormalities in solid surfaces and the direct use the sliding velocities as boundary conditions. This work is to specify explicitly the slip velocity at the wall, which is generally a function of stress at the wall, the geometric dimensions and temperature. And this

dependence of slip velocity at the wall of these factors can be found from viscometric measurements. Next considering the case of plane Poiseuille flow with allowance for slippage of the polymer material at the boundary, the system of equations of the modified Vinogradov and Pokrovskii rheological model describes non parabolic velocity profile in the gap between parallel plates, which is confirmed by experimental data. The dependences obtained can be used in the study of more complex flows. This is shown by the example of the calculation of the three-dimensional velocity profile of a nonlinear viscoelastic fluid in a channel with a square cross-section.

Wednesday 18:10 Foyer Sirene

PO123

Breakup phenomena of immersed viscous jets: experiments and numerical simulations

Claudiu Patrascu and Diana Broboana

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The paper is concerned with the experimental investigations and numerical modelling of the immersed liquid jets breakup phenomena. The main aim of the study is to quantify the influence of the viscosity ratio between the two fluids on the breakup length. There are also analysed: (i) the influence of the viscosity shear thinning on the phenomena (using correlations between experiments and numerical simulations), (ii) the elasticity influence on the immersed jet stability and droplet detachment. In experiments are used as working fluids water - glycerol and PAA water solutions (for the liquids jets), immersed in an oil at rest (as the surrounding medium). The liquid jets are introduced in a tank through a capillary of 0.6 mm diameter, the input flow rate being controlled by a special designed syringe pump setup. Numerical simulations are performed using different Carreau models, corroborated with the VoF subroutine implemented in the ANSYS Fluent code.

Wednesday 18:10 Foyer Sirene

PO124

Effect of confinement on natural convection heat transfer from a circular cylinder in shear-thinning fluids

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In this work, free convective heat transfer from an isothermal horizontal cylinder (of diameter D) in power-law fluids and confined between adiabatic vertical walls has been investigated numerically. The governing differential equations have been solved over wide ranges of conditions as: Rayleigh number ($10^3 \leq Ra \leq 10^6$), Prandtl number ($5 \leq Pr \leq 100$), power-law index ($0.3 \leq n \leq 1.0$) and confinement ratio ($2 \leq W/D \leq 10$), where W is the width of the channel. The flow and heat transfer results have been interpreted in terms of streamlines and heatlines, velocity profiles, drag coefficient, local and average Nusselt number as functions of the aforementioned governing parameters. Depending upon the relative contributes of shear-thinning viscosity, buoyancy (Gr) and the wall confinement, the overall heat transfer from the cylinder may be promoted or impeded. Overall, for Newtonian fluids, it is possible to obtain up to of 50% enhancement in heat transfer for the case of the minimum confinement, i.e., $W/D = 10$ and at the highest Rayleigh number, $Ra = 10^6$ employed in this work. At high Rayleigh and/or Prandtl numbers (strong convection), shear-thinning viscosity exerts a positive influence on the Nusselt number while the reverse trend is observed at small values of these parameters (conduction dominant region). The present average Nusselt number results are consolidated via a simple expression involving (W/D), Ra and power-law index (n).

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PO125

Comparison of discontinuous shear thickening in different geometries

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Discontinuous shear thickening (DST) is observed in highly concentrated suspensions of microparticles which are initially not aggregated thanks to the use of a surfactant. When the applied shear stress overcomes a critical value the surfactant molecule does not prevent the surface of the particles to come into frictional contacts provoking a sudden jamming of the suspension and a strong reduction of the shear rate if the shear stress is imposed. If, on the contrary, a ramp of shear rate is imposed we observe a strong jump of stress. We shall compare the results obtained for the same suspension in different geometries (plate-plate; cone-plate; concentric cylinders, capillary flow and different flow regimes (imposed shear rate or imposed shear stress). The lack of reproducibility of certain experiments and the rôle of sedimentation and/or migration of particles will be analysed in view of recent experiments made in microgravity and in a closed cell. Mastering the reproducibility of the DST is a key feature for applications, in particular those concerning the control of the transition with the help of a magnetic field in magnetorheological suspensions.

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PO126

Rheological demonstration of alteration in the heavy crude oil fluid structure upon addition of nanoparticles

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Nanotechnology offers potentially disruptive methods to improve the mobility of heavy oil through viscosity reduction. In this sense, the objective of this work is to probe changes in the viscoelastic network of asphaltene intrinsic to heavy oil structure upon addition of fumed SiO₂ nanoparticles, using dynamic rheological techniques. The effects of the addition of nanoparticle on heavy oil are patently reflected as a viscosity reduction and a non-Newtonian shear thinning behavior. The best concentration of nanoparticles over the wide range evaluated is obtained at 1000 mg/L, which was evaluated at 288, 298 and 313 K. The viscosity reductions were found to range from 12 to 45% in the shear rate range 0-100 s⁻¹. Viscoelastic moduli were measured in dynamic tests in a frequency

range from 0.1 to 100 rad/s at a strain of 2% and at 288, 298 and 313 K. For heavy crude oil without nanoparticles, the magnitude of the loss modulus G'' and its growing trend suggest the existence of a viscoelastic network of asphaltenes and auto-associative behavior. For all tests, the loss modulus, G'' , is always greater than the storage modulus G' , suggesting that the crude oil is more viscous than elastic, except at 313 K and at a frequency > 30 rad/s, where G' is greater than G'' . By adding 1000 mg/L of nanoparticles, the magnitude of the viscoelastic moduli is reduced compared to values for crude oil without nanoparticles. The results conclusively prove that nanoparticles disrupt the viscoelastic network formed by asphaltenes aggregates in the presence of resins, and this causes the viscosity reduction in heavy crude oil. This conclusion is further supported by results obtained when nanoparticles were added to de-asphalted oil (DAO) and light oil with a low asphaltene content; in both cases the viscosity increases, suggesting that the nanoparticles interact directly with asphaltenes in crude oil.

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PO127

Effect of SiO₂-based nanofluids in the reduction of naphtha consumption for heavy and extra-heavy oils transport: economic impacts on the colombian market

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Techniques commonly used to improve the heavy crude oil transport includes the addition of solvents, as they contribute to reducing oil viscosity. However, the high consumption of these solvents increases transportation costs and generates different environmental risks, making it an unattractive technique. The objective of this study is to evaluate the effect of nanofluids as additives to optimize the transport of heavy crude oil using steady-state rheological measurements and dynamic flow tests. The use of these additives produces viscosity reduction for heavy (HO) and extra heavy (EHO) crude oils. Four nanofluids were prepared using different solvents and fumed silica nanoparticles. Mixtures with naphtha were prepared to reduce the viscosity of the crude oil as to attain mobility targets (400-500 cP at 311K). To this end, 27% and 63% v/v of naphtha were required for heavy and extra-heavy crude oils, respectively. Steady-state rheological measurements were conducted at 311K, and the best performing material turned out to be the nanofluid composed of 1000 mg/L of SiO₂ and biodiesel. This nanofluid yielded a reduction in the consumption of naphtha of approximately 50%. Consequently, dynamic flow tests in a pipeline were conducted at 298 and 313K for both crude oils. The same pressure differential was obtained by adding 10% of the nanofluid and reducing the consumption of naphtha by more than 50% in all mixtures. Our results show that the best-performing nanofluid can serve as an optimizing agent for the transport conditions of heavy and extra-heavy crude. The proposed technology was evaluated through an economic analysis that shows a potential reduction of dilution costs of almost 50%, equivalent to more than USD \$2.5 million per day, as well as a decreased energy consumption. Additionally, a discussion on environmental impacts are presented. A nanofluid-based technology could generate savings in both energy and fuel consumptions.

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PO128

A novel method for heavy oil transport

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In [1] we introduced a novel methodology for efficient transport of heavy oil via a triple layer core-annular flow. Pumping pressures are significantly by concentrating high shear rates to a lubricating layer, while ideas from Visco-plastic lubrication [2, 3] are used to eliminate interfacial instabilities. We purposefully position a shaped unyielded skin of a visco-plastic fluid between the transported oil and the lubricating fluid layer. The shaping of the skin layer allows for lubrication forces to develop and balance the density difference between the fluids. Here we address the sculpting of the shaped skin within a concentric inflow manifold. First we present the results of a long-wavelength/ quasi-steady analysis, which allows for us to predict maximal and minimal variations in skin thickness, while maintaining a constant flow rate of the transported oil. Secondly, we use the simple model to provide inputs to an axisymmetric triple layer computation, showing development of the streamwise skin profile and establishment of the flow. For this we use a finite element discretization with the augmented-Lagrangian method to represent the yield surface behaviour accurately and a PLIC method to track the interface motion.

[1] Sarmadi, P. et al. (2017). Physical Review Fluids, 2(4), 044302. [2] Moyers-Gonzalez, M. A. et al. (2004). Journal of Fluid Mechanics, 506, 117-146. [3] Hormozi, S. et al. (2014). Physics of Fluids, 26(9), 093101.

Wednesday 18:10 Foyer Sirene

PO129

Experimental investigation of the accuracy of the modelled frictional pressure loss for annular pipe flow based on rheological characterization of a non-Newtonian drilling fluid

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During drilling operations, it is important to accurately model the pressure profile in the well to control the drilling process and achieve a more efficient drilling program. The frictional pressure loss is the component with the highest uncertainty compared to the hydrostatic component. It is therefore important to understand the uncertainties related to the modelling of this pressure loss. The pressure gradient is calculated with the fluid rheological properties as input. This study compares the modelled frictional pressure loss using the rheological characterization of a drilling fluid as measured with an Anton Paar high-precision rheometer with the actual pressure loss measured in a flow loop experiment at the University of Stavanger. The rheometer measurement is carried out with shear rate as control parameter, while in pipeline flow the readily available control parameter is the pressure gradient. An important difference lies in uncertainties in the relation between shear rate and pressure gradient in pipelines. The main contributors to the uncertainties are investigated with focus on model simplification, uncertainties related to the measurements and instabilities

related to Taylor Vortices for transitional and turbulent flow. The drilling fluid used in this study is the aqueous solution of Poly-Anionic Cellulose (PAC) with viscoelastic shear thinning behaviour. In laminar flow the viscous forces dominate and will be representative also for flow in annulus downhole during drilling. However, the composition of the drilling fluid is complex and will during circulation be invaded by solid particles. Therefore, another goal of this study is to investigate the impact of particles on the predictability of frictional pressure loss. By identifying and quantifying the main sources of uncertainties for pressure loss modelling this work shall contribute to optimize the drilling process, in a more efficient and safe manner. The results are of importance also for other industries dealing with non-Newtonian fluids.

Wednesday 18:10 Foyer Sirene

PO130

Application of a dehydrothermal treatment to modulate crosslinking of a soy protein-based isolate processed through injection moulding

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A protein based porous matrix was obtained through five-step process: first, a mixing stage of the protein and a plasticizer took place in a counter-rotating blending device at 50 rpm for 10 min at room temperature, leading to an homogenous blend; second, the obtained blend is moulded in a lab-scale injection moulding machine, selecting adequate processing parameters in order to fill the mould and obtain a bioplastic; third, the bioplastic is submitted to a dehydrothermal (DHT) treatment, being stored at 50 °C for a certain period of time; fourth, the dehydrated bioplastic is immersed in a water bath for 24 h, resulting in the plasticizer loss; and finally, a fifth stage in which the hydrated matrix is frozen-dried resulting in a porous matrix. The described process permits the production of materials that, when conveniently formulated and processed, may produce the so called superabsorbent materials. These materials are able to absorb great amounts of water and may have applications in different industries (e.g. diapers, hygienic tissues, agriculture). The interest of a superabsorbent material based on proteins lies on the high biodegradability of these materials, compared to the traditional acrylic derivatives. A Soy Protein Isolate (SPI) has been used for the study, being a by-product of the soy oil industry rich in polar aminoacids like glutamic or aspartic acid, which may favour the formation of a hydrophilic matrix. The third stage of the proposed process allows the modulation of the cross-linking within the protein structure, especially when the moulding conditions used in the previous stage have been mild (70°C). Thus, water uptake capacity and rheological properties of the matrices produced have been evaluated at different DHT times. In general terms, matrices with higher water uptake capacity and lower viscoelastic properties were obtained at shorter times, when cross-linking have not developed much further than that achieved in the injection mould.

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PO131

Startup of waxy crude oils in tubes

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The startup of waxy crude oils in tubes is a great problem for flow assurance. After a period of shutdown in oil production the waxy precipitates and the oil starts to behave like a very complex non-Newtonian material. In fact, it behaves like a thixotropic viscoelastic material. For flow assurance, the minimal pressure gradient to re-start the flow must be predicted and it is common to use the relation $DP=2(L/R)\tau_0$, where L and R are, respectively, the tube length and radius and τ_0 is the yield stress of the waxy crude oil. Our objective here is to verify how realistic is such an expression, since it does not consider, for example, the wall slip phenomenon, which can truly play an important role. We use an apparatus basically composed by a piston that pushes the waxy oil inside a tube. The necessary pressure to start the flow is taken into account and an effective yield stress is inferred by means of the equation above. By doing so, such an effective yield stress is compared with that measured in a rotating rheometer. Our main conclusion is that the slipperiness is really important, but it depends on many parameters as the kind of oil and the history temperature of the material.

Wednesday 18:10 Foyer Sirene

PO132

Effect of demulsifiers on the rheological behavior of asphaltene interfaces

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Asphaltenes are well known to strongly stabilize water-in-oil emulsions that are formed during production and transportation of crude oils. This can be highly undesirable due to the increased pumping costs associated with the higher viscosity of emulsions, to issues in downstream water separation, among other problems. Different approaches can be used to destabilize these emulsions in oilfields, such as application of an electrical field and/or the addition of demulsifiers. Demulsifiers, also known as emulsion breakers, are surface-active materials and are typically added to the continuous crude oil phase to "break" the emulsions by enhancing coalescence, the precise mechanisms by which still needs to be better understood. Specifically, the interfacial rheological behavior has been shown to be very important to assess the stability of emulsions. Thus, in this work, we investigate the effect of different commercial demulsifiers on asphaltene laden interfaces. Interfacial shear rheology tests were carried out with a double wall-ring geometry mounted on a stress-controlled rheometer. First, asphaltene films at the liquid-liquid interface were characterized. They show high elasticity, with increasing moduli as the surface coverage is increased, and typical soft-glassy behavior. Then, different demulsifiers were added to these interfaces and their effects on the viscoelastic moduli were monitored. Interestingly, significant differences in the performance of different demulsifiers are observed.

Wednesday 18:10 Foyer Sirene

PO133

Rheology of Cystic Fibrosis SputumLukas J. Böni¹, Thomas Radtke², Peter Bohnacker¹, Christian Benden³, Holger Dressel², and Peter Fischer¹¹Health Science and Technology, ETH Zürich, Zürich, Zürich 8092, Switzerland; ²Epidemiology, Biostatistics and Prevention Institute, University of Zürich, Zürich, Switzerland; ³Division of Pulmonology, University Hospital of Zürich, Zürich, Zurich 8091, Switzerland

People with cystic fibrosis (CF) suffer from a sticky and thick sputum, which obstructs airways and impedes clearance and thus can cause chronic lung infections. Gel-forming mucins are a main component in the sputum and they are critical to the onset of the disease as well as in determining sputum flow. Rheology is used to study viscoelastic properties of CF sputum and can help to gain insight in flow properties during respiratory clearance processes such as ciliary beating and coughing. Despite the increasing use of shear rheology in medical CF research, little is known about inertia limitations at high frequency oscillations (100 rad/s), which are commonly used to mimic coughing. We therefore investigated the flow behavior of CF sputum in oscillatory shear. We found that the low sample modulus (~10 Pa) and the onset of instrument inertia limits measuring frequencies to 10 rad/s to mimic coughing events, which is one order of magnitude lower than the commonly used frequency. Furthermore, using a smooth and a roughened plate geometry, we find that the roughness of the plate geometry has little effect on small amplitude oscillations but shows substantially different results during large amplitude oscillations and yield measurements. Both protocols are potentially important to study clearance performance. Our findings will support future medical studies in choosing the best possible measurement protocol and geometry for CF sputum rheology and the raised awareness for limitations will assist the interpretation of obtained data.

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PO134

Atypical, non-cubical power law scaling of asymptotically nonlinear viscoelasticity of capillary suspensionsIrene Natalia¹, Randy Ewoldt², and Erin Koos¹¹Soft Matter, Rheology and Technology, KU Leuven, Leuven 3001, Belgium; ²Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, United States

Typically, constitutive models report that the leading order term of the asymptotically nonlinear response occurs at a scaling $\sigma \sim O(\gamma^3)$. This scaling can be explained by a multiple integral expansion of the Boltzmann superposition [1]. Here, we report atypical, non-integer medium-amplitude oscillatory shear (MAOS) power law scaling for capillary suspensions, that is, particle suspensions in a two-fluid system with capillary interactions. Distinct power law exponents are found for the storage and loss moduli and these exponents vary based on the sample composition. The addition of small amounts of an immiscible secondary fluid to a suspension can dramatically change the rheological behavior of the suspension from a fluid-like to gel-like state [2]. This transition is caused by strong attractive capillary force between the particles and two fluids producing a sample-spanning network. Capillary suspensions exist in two states: a pendular state when the secondary fluid preferentially wets the particles and a capillary state when the bulk fluid is preferentially wetting. Blackwell and Ewoldt also observed non-integer scaling experimentally with a Carbopol system and they presented a theory wherein non-integer scalings can be predicted from a thixotropic-viscoelastic constitutive model [3]. For the capillary suspension studied here, the capillary bridges rupture under shear and then rebuild the network upon cessation. Such thixotropic behavior might indeed be the origin of the atypical scaling. However, such a scaling might also occur because of the fractal microstructure in the percolated sample-spanning network or due to violation of the simple potential field. These theories are compared to direct observations of the network structure using confocal microscopy. The influence of the relative secondary fluid volume will also be discussed for both capillary and pendular states.

[1] Davis, W. M. & Macosko, C. W. (1978). Journal of Rheology, 22(1), 53-71. [2] Koos, E. & Willenbacher, N. (2011). Science, 331(6019), 897-900. [3] Blackwell, B. C. & Ewoldt, R. H. (2016). Journal of Non-Newtonian Fluid Mechanics, 227, 80-89.

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PO135

Liquid crystalline domains and associated sol-gel transition in cellulose-ionic liquid-water mixturesAshna Rajeev, Abhijit P. Deshpande, and Madivala G. Basavaraj¹Chemical Engineering, Indian Institute of Technology Madras, Chennai 600036, India

Liquid crystalline gels find application in different fields such as, display and storage devices, sensors etc. Recently it was reported that cellulose dissolved in 1-ethyl-3-methylimidazolium acetate (EmimAc) shows sol-gel transition accompanied by a liquid crystalline phase transition at cellulose concentrations > 10 wt%. As it is possible to obtain liquid crystalline gelation in solutions of rod-like polymers by tuning the solvent environment, we exploit this principle to modulate a series of phase transitions in solutions of microcrystalline cellulose (MCC) of concentration ranging from 5 - 20 wt% in 1-allyl-3-methylimidazolium chloride (AmimCl) by the addition of water. The phase behaviour is studied by means of rheology and by means of polarisation optical microscopy (POM). Water, being an anti-solvent causes reduction in the solvent quality which leads to the aggregation and self-assembly of cellulose chains and eventually forms optically anisotropic domains. We observed the characteristic planar textures of non-aligned Cholesteric phases and regions of spherulitic like textures at low (5 wt %) and high (20 wt %) concentrations of cellulose respectively. The corresponding rheological observations revealed the sol-gel transition and network formation at high concentrations of water. The melting and gel-sol transition of the anisotropic domains in MCC/AmimCl/water mixtures with increase in temperature by means of hot-stage POM, differential scanning calorimetry (DSC).

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PO136

Sol-gel transition of high methoxy pectinsDaniela Giacomazza¹, Donatella Bulone¹, Rosamaria Marino², Pier L. San Biagio¹, and Romano Lapasin³¹*Istituto di BioFisica, Consiglio Nazionale delle Ricerche, Palermo, Italy;* ²*Silvateam Food Ingredients, Rende, CS, Italy;* ³*Department of Engineering and Architecture, University of Trieste, Trieste, TS 34128, Italy*

High methoxy pectins (HMP) form a three-dimensional network at acid pH and in the presence of large amounts of sugars or other co-solutes. The gelation mechanism is mainly due to interchain associations which are promoted by attractive interactions, by hydrogen bonds and hydrophobic interactions. Indeed, hydrogen bonds are favored at low pH and hydrophobic interactions between the methoxyl groups are promoted by high sugar content and preferential hydration effects. Simultaneously, a further contribution to the dynamical arrest of aqueous concentrated HMP solutions comes from the jamming condition which is attained by associated polymer chains at high sugar content. The structuring kinetics of aqueous HMP solutions having different polymer concentration and equal sucrose content can be conveniently monitored in oscillatory shear conditions by means of time-resolved mechanical spectroscopy, being the increase of viscoelastic moduli sufficiently slow. So doing, the self-assembly pathway of the polymer chains can be appropriately described through the time evolution of its mechanical spectra. A plateau region appears in the G' - ω profile after a critical time and then it becomes more and more extended, shifting toward higher modulus values with increasing times. Following the Winter-Chambon criterion, the sol-gel transition and the corresponding gel time, t_g , can be individuated with acceptable approximation from the common intersection of the $\tan \delta$ vs time curves determined at different frequencies. Moreover, by assuming self-similarity of the incipient polymeric network, a fractal dimension df can be deduced from the analysis of the mechanical spectra at the gelation time, so giving a measure of the different degree of compactness of the HM protein networks at different polymer and sucrose concentrations.

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PO137

The effect of amine functionalities of poly(cyclooctene) on 3D network formationTanja Tomkovic¹, Damon J. Gilmour², Mitchell R. Perry², Laurel L. Schafer², and Savvas G. Hatzikiriakos¹¹*Chemical and Biological Engineering, The University of British Columbia, Vancouver, Canada;* ²*Chemistry, The University of British Columbia, Vancouver, BC V6T-1Z1, Canada*

Poly(cyclooctene) with secondary aryl-amine functionalities were synthesized using ring-opening metathesis polymerization combined with hydroaminoalkylation reaction. The resulting polymers were characterized by means of ¹H NMR and IR spectroscopies, gel permeation chromatography (GPC), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and solution and melt rheology. A plethora of distinctively different rheological behavior was obtained by introducing various functionalities that exhibit different hydrogen bonding strengths. These novel materials reveal an evident transition from liquid- to solid-like behavior through gel formation. The detailed rheological study demonstrates the formation of the 3D network formed by physical crosslinking of hydrogen bonds.

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PO138

Rheology of mixed sodium alginate–gelatin hydrogelsN. Voron'ko¹, L. Kuranova², and S. Derkach¹¹*Chemistry Department, Murmansk State Technical University, Murmansk, Russia;* ²*Department of Food Production Technology, Murmansk State Technical University, Murmansk, Russia*

Polyelectrolyte complexes of polysaccharide with gelatin are a promising basis for the creation of new materials used in biotechnology, pharmaceuticals, the food industry and other sectors related to human health and nutrition. Organoleptic characteristics of these materials are largely determined by their rheological parameters, the evolution of which is determined by the molecular mechanism of complexation of a complementary biopolymer with gelatin. In this study the effect of sodium alginate-gelatin complexation on the rheology of hydrogels formed from the aqueous extract of alginate-containing algae *Fucus vesiculosus* in the presence of gelatin was investigated. It is shown that the addition of gelatin causes the gel formation in the bulk of the *Fucus* extract. The increase in the η_{gel} leads to an exponential growth in the gel rheological characteristics. In the region of small deformation, gels exhibit a solid-like behaviour in a wide frequency range. Adding gelatin causes a nonadditive increase in the elastic modulus G' and a decrease in $\tan \delta$ of hydrogels, i.e., the enhancement of elastic and weakening of the viscous properties of hydrogels. The observed changes in the rheological properties of the hydrogels are explained on the base of the alginate-gelatin complexation model at the microscopic level. It has been shown that the polyelectrolyte complexes are formed due to electrostatic interactions and hydrogen bonds between both biopolymers. A significant difference between the morphology of gelatin hydrogels and mixed sodium alginate-gelatin hydrogels was found. In the structure of the latter, spherical particles are found that are aggregates of alginate-gelatin polyelectrolyte complexes. They play the role of additional junctions in the gel network and lead to the evolution of rheological properties.

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PO139

Saint-Venant simulations of granular flows over a basal surface with topographyIoan R. Ionescu¹, Oana Lupascu², and Silviu Vasile³¹*LSPM, University Paris 13, Villetaneuse 93430, France;* ²*IMAR, Bucharest, Romania;* ³*Institute of Mathematical Statistics and Applied Mathematics, Bucharest, Romania*

Dry granular flows over a basal surface with a topography are simulated by using a Saint-Venant model of dense avalanches developed in [I.R. Ionescu, Viscoplastic shallow flow equations with topography, *J. Non-Newtonian Fluid Mechanics* 193 (2013), 116-128]. The two dimensional model is associated to the $\mu(I)$ -rheology, a Drucker-Prager yield stress, a variable viscosity and basal Coulomb friction. The numerical method makes use of an implicit time discretization and a FE(Finite Element)-

DG(Discontinuous Galerkin) spatial discretization. Quantitative comparison between experimental and numerical changes with time of the thickness profiles and front velocity makes it possible to strongly constrain the rheology. In particular, we show that the use of a variable or a constant viscosity does not change significantly the results provided that these viscosities are of the same order.

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PO140

Emergence and persistence of flow inhomogeneities in the yielding and fluidization of dense soft solids

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The response to shear of the dense soft solids features a stress overshoot and a persistent shear banding before reaching a homogeneously flowing state. In 3D large scale simulations we analyze the time required for the onset of homogeneous flow, the normal stresses and structural signatures at different shear rates and in different flow geometries, finding that the stress overshoot, the shear band formation and its persistence are controlled by the presence of overconstrained microscopic domains in the initially solid samples. Being able to identify such domains in our model by prevalently icosahedrally packed regions, we show that they allow for stress accumulation during the stress overshoot and that their structural reorganization controls the emergence and the persistence of the shear banding.

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PO141

Effect of external vibrations on the rheology of granular suspensions

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Effect of external vibrations on the rheology of granular suspensions In this work we investigate in details the rheology of dense vibrated gravitational suspensions. We study the rheology in the stationary state by using a stress imposed rheometer (spectroscopy mechanics) coupled with a vibration cell, we show that applying well-controlled mechanical vibrations allows the control of the suspension viscosity by suppressing the apparent yield stress which is largely the cause of flow jamming. We link this apparent rheology with the dynamics at the grain scale using PTV measurements. Refractive-index matching technique are used to visualize inside the sample and therefore to study the rearrangements of the grains at the local scale. When no vibrations are applied, we evidence the non-locality of the rheology and extract a correlation length ($\sim 2D$) that does not depend on the applied shear rate. This value is in agreement with previous numerical simulations from the literature. When vibrations are applied, the correlation length vanishes and the rheology is related to the time a particle need to move from a fraction of grain diameter. We show that the rheology is controlled by the competition between the reorganization time induced by the flow and the reorganization time induced by vibrations. We evidence vibrations homogenize the suspension and make the rheology local. We discuss the influence of particles size, suspending fluid viscosity and vibration parameters and demonstrate that the grains dynamics is controlled by the ratio between the lubrication stress and the granular pressure. This work evidences the major role played by the vibration induced lubrication stress on the liquefaction of vibrated granular suspensions.

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PO142

Constitutive model for elastoviscoplastic irreversible time-dependent materials

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We present results of a thorough rheological characterization of cement pastes, performed according to a carefully developed protocol. The rheological behavior observed includes viscoplasticity, thixotropy at the early stages after preparation, and irreversible time dependence once the curing process sets in. We propose a constitutive model for this type of rheological behavior that consists of two differential equations, namely an Oldroyd-B-like equation that relates the rate of strain tensor with the Cauchy stress tensor and a kinetic-type differential equation that gives the time evolution of the fluidity. The material functions that arise in the model are easily determinable from standard rheological measurements. Curing is considered by introducing a time-dependent yield stress that is also determined experimentally. A comparison between the model predictions and experimental results attests the robustness of the proposed model.

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PO143

Direct links between dynamical, thermodynamic and structural properties of liquids: Modelling results

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We develop an approach to liquid thermodynamics based on collective modes including high-frequency transverse modes [1]. We perform extensive molecular dynamics simulations of noble, molecular and metallic liquids and provide the direct evidence that liquid energy and specific heat are well-described by the evolution of high-frequency transverse modes propagating above the Frenkel (hopping) frequency. The agreement between predicted and calculated thermodynamic properties is seen in the notably wide range of temperature spanning tens of thousands of Kelvin. The range includes both subcritical liquids and supercritical liquids [2]. We discuss interrelationships between structure, dynamics and thermodynamics of liquids and supercritical fluids and the structural crossover at the Frenkel line [1].

[1] Trachenko, K. & Brazhkin, V. V. (2015). Reports on Progress in Physics, 79(1), 016502. [2] Wang, L. et al. (2017). Physical Review E, 95(3), 032116.

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PO144

A model granular suspension in a yield-stress fluidYujie Jiang, John Royer, and Wilson Poon*School of Physics and Astronomy, The University of Edinburgh, Edinburgh, United Kingdom*

While there has been considerable progress understanding the rheology of simple suspensions of particles in a Newtonian liquid, many industrial suspensions (cement, drilling fluids etc ...) are far more complex, composed of multiple components that are heterogeneous in both particle size and interaction type. Here we develop a model binary suspension composed of coarse, non-Brownian, repulsive particles and smaller, attractive colloidal particles. We use silica particles for both species and modify the small particle surface chemistry to induce attractive interactions, allowing us both to tune the strength of attraction and refractive index match both particle types. Individually, suspensions of the large repulsive particles exhibit shear thickening while the attractive colloidal particles form a yield stress gel. Using a combination of rheology and confocal imaging, we probe the dynamics and microstructure of the combined suspensions to explore the interplay between the different components.

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PO145

Multi-scale adhesion phenomena between overlay and concrete substrate: rheology and mechanicsLukasz Sadowski*Faculty of Civil Engineering, Wroclaw University of Science and Technology, Wroclaw, Wroclaw 50-370, Poland*

The adhesion between overlay and concrete substrate depends on the rheological, physicochemical and mechanical state of joined materials. Recently the interest in the improvement of the rheological and mechanical aspect of adhesion phenomena in multi-layer concrete elements has considerably increased. This is mainly because between newly laid overlay an "interphase" is formed. It is opposite to an "interface" which is present between hardened layers. To reach a desired functionality and durability of newly constructed and repaired multi-layer concrete structures, proper and improved descriptors of this interphase are needed. In recent years, more activities to obtain the desired adhesion will be made at lower scales of observation. These activities involve for example the use of proper existing concrete substrate surface treatment. Thus, it is necessary to develop multi-scale and multi-sensor approach to evaluate this phenomena. With this in mind the aim of this work is to make such an attempt using various techniques at different observation length scales.

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PO146

Compaction of granular suspension: global and local studyNicolas Louvet, Sébastien Kiesgen de Richter, Maude Ferrari, and Mathieu Jenny*Université de Lorraine, Vandoeuvre-les-Nancy 54505, France*

The study of the compaction of granular matter is of great importance. Indeed, the compacity is a key parameter to control the rheological behavior of such dispersed materials. While for dry granular the compaction is well documented, the case of wet granular suspensions paid less attention and some questions remain. In this study we investigate the compaction dynamics of a granular suspension submitted to mechanical vibrations of given amplitude and frequency. Global and local time evolution of the compacity is measured by digital imaging and magnetic resonance imaging or impedance spectroscopy respectively. For the whole range of parameters studied (vibration amplitude and frequency, fluid viscosity and bead size) we report a two stages compaction dynamics: a fast stage at short time where a compaction front propagates through the granular packing and at large time a slow stage where the granular material compacts homogeneously. Results are analyzed in term of lubrication Peclet number³ which balances the lubrication stress induced by vibrations and granular pressure.

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PO147

Dynamic sorption tests for the analysis of relaxation behavior of glassy polystyrene-toluene systemsFerruccio Doghieri¹, Davide Pierleoni¹, Matteo Minelli¹, Giuseppe Mensitieri², Giuseppe Scherillo², and Valerio Loiano²¹DICAM, Università di Bologna, Bologna 40131, Italy; ²Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy

A novel procedure is here proposed for the characterization of structural relaxation behavior of polymer-solute systems in the vicinity of glass transition as induced by sorption/desorption of the solute species. An Equation-of state approach (PC-SAFT), conveniently extended to the case of glassy states (NET-GP), is here used to describe the thermodynamic properties of the polymeric system across the glass transition and it is combined with a non-linear rheological model for volume relaxation in order to describe the variation over time of apparent vapor solubility in the system. Based on that, in this work a general procedure is proposed for the experimental characterization of structural relaxation induced by vapor sorption in glassy systems. The procedure is applied in this work to retrieve the relaxation time of polystyrene-toluene system around room temperature and a general mass transport model endowed with proper expression for structural relaxation is finally used to interpret the kinetics in a standard sorption experiment in the same system. The extension of the procedure to the characterization of structural relaxation in a broad range for temperature and solvent fugacity is expected to provide the basis for the representation of several anomalous characteristics of mass transport kinetics in amorphous glassy polymers. The latter is indeed both of great interest in fundamental research and of relevance in a number of different applications, from ageing of gas separation membrane to working conditions for drug delivery devices.

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PO148

Rheology of dense granular fluids: experiments

Olfa Lopez, Till Kranz, and Matthias Sperl

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Granular materials have grown to be a material of utmost importance for a variety of domains ranging from geophysics, food and pharmaceutical industry or space exploration. Particulate solids have been studied for centuries in the framework of engineering and geology, but many phenomena are yet to be fully understood, posing a challenge to material science. As the shear stress varies over many orders of magnitude upon changing the flow conditions, obtaining reliable and reproducible quantitative measurements remains a challenge. Packing fractions below the dense static packing can only be studied in systems of reduced gravity. To reduce the effect of gravity, we perform shear experiments on a fluidized granular bed. Those measurements are obtained using the Modular Compact Rheometer (MCR) 102 from Anton Paar, which allows a range of torque going from 5 nN.m to 200 mN.m at rotating speed up to 84 radians per second. The fluidization bed being a closed space, particles from diameter of 5 microns can be tested. The motor of the machine is supported by an air bearing, ensuring a frictionless synchronous movement of the rotor, and therefore a torque resolution of 0.5 nN.m. The measuring system is a central cylinder, with a surface engineered to provide only powder-powder contact. Flow curves relating shear stress to shear rate are obtained for shear rates up to 200 s⁻¹ and a range of packing fractions. They provide material for observation of rheological regimes comprising Newtonian, Bagnoldian, shear thinning, and shear thickening behaviours. This work corroborates theoretical prediction of the existence of flow regimes at finite shear rates and densities [1].

[1] Kranz, W. T. et al. (2017). arXiv preprint arXiv:1710.04452.

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PO149

Acoustic probing of a ball sinking in horizontally vibrated granular sediments

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A convenient method to determine the viscosity of a fluid is to drop a high-density ball in it. The ball will first accelerate before it reaches a terminal velocity that is related to the viscosity of the fluid via Stokes' law. Instead, in a yield stress fluid like a granular suspension, the ball will stop sinking at a certain depth due to friction between the solid particles. However, understanding an intruder sinking in quicksands remains a conceptual and practical challenge: there are very few direct experimental investigations in realistic 3D opaque dense granular suspensions. Here, we develop acoustic probing to investigate the dynamics of a steel ball sinking in the glass bead packing saturated by water. The technique is based on the detection of coherent echo that survive the scattering in the dense granular suspension. We show that the motion of the ball in a vibrated granular suspension is consistent with the frictional rheology revealed in dense granular media. Unlike the classic liquefaction related to the pore pressure increase, we find that the decrease of solid friction between beads induced by shear vibration is the responsible mechanism for the fluidization of solid skeleton and the ball sinking. Indeed, the direct investigation of generated shear waves propagating through granular skeleton reveals a drastic elastic softening when the vibration increases.

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PO150

Time-resolved structural evolution of microgels in their collapse transition

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Microgels exhibit substantial conformational changes upon modifications of their environmental conditions such as temperature, pH, or composition of the solvent. A swollen microgel is characterized by a fuzzy surface of a finite-size macromolecular network, whereas a collapsed microgel resembles a colloidal particle with homogeneous density and a sharp surface. Here, we present simulation results of the structural evolution during the microgel-to-particle transition upon solvent exchange. Thereby, a coarse-grained model for the tetra-functionally crosslinked polymer chains is used and the solvent is described explicitly by the multiparticle collision dynamics method. The latter insures the correct account for hydrodynamic interactions. We find a two-stage collapse. In a first, very fast process, collapsed clusters are formed at the periphery leading to an intermediate, hollowish core-shell structure that slowly transforms to a globule. Moreover, large voids are observed in the microgel shell during collapse, which indicate that solvent trapping inside the microgel does not play a significant role in the slow collapse process. This structural evolution is independent of the type of stimulus, and thus, applies to instantaneous transitions as in a temperature jump or to slower stimuli that rely on the uptake and/or exchange of active molecules with the environment. An increase of the relaxation time of the network polymers through an increase of the polymer length does not alter the two-stage collapse process. However, the collapse speed increases with increasing quenching depth. In addition, the collapse speed is correlated with the speed of cononsolvent transport into the microgel. This indicates that the rate limiting factor in temperature-induced collapse can be different from that driven by cononsolvency or change of pH. Most importantly, our analysis reveals that the kinetics in the fast collapsing regime is driven by hydrodynamic interactions.

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PO151

Rheological behavior and thermal stability of hydrolyzed polyacrylamide (HPAM) based polymeric solutions in presence of SiO₂ nanoparticles

Lady J. Giraldo Pedroza¹, Sebastian Llanos Gallo¹, Richard D. Zabala², Gustavo A. Maya Toro², Farid B. Cortés Correa¹, and Camilo A. Franco Ariza¹

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Polymer injection is one of the most commonly used techniques for enhanced-oil-recovery (EOR), which aims at improving the sweep efficiency in oil reservoirs. Despite its effectiveness in EOR improvement, this method is riddled with limitations mainly due to polymer degradation by either the effects of the temperature, salinity, stress and/or the presence of an oxidative atmosphere. Detrimental effects tend to compound as to degrade the effectiveness of traditional polymers. The objective of this study is to investigate the effects of SiO₂ nanoparticles on improving the rheological behavior and inhibition of the thermal degradation of HPAM solutions. The SiO₂-HPAM interactions were evaluated through polymer adsorption onto nanoparticles, rheological studies, and evaluation of oxygen on thermal stability. The nanofluids were prepared by adding a fixed concentration of nanoparticles to an HPAM-containing aqueous solution. The adsorption isotherms of HPAM over the SiO₂ nanoparticles were obtained in batch-mode experiments. The adsorption isotherms were modeled using Langmuir, Freundlich and SLE models. The best fitting was obtained using the SLE model. Rheological tests in the temperature range from 25 to 70°C showed a pervasive non-Newtonian behavior for all the SiO₂-HPAM combinations tested. The Herschel-Bulkley and Carreau models were used to describe the rheological behavior of the prepared nanofluids with RSME% values better than 0.3. The thermal stability of polymeric solutions in the absence and presence of nanoparticles was evaluated under inert and oxidative atmospheres at 70°C for 14 days. It was observed that a lower degree of degradation resulted for polymeric solutions in the presence of nanoparticles and in the absence of oxygen, indicating that SiO₂ nanoparticles increased the viscosity and inhibit HPAM degradation and subsequently improve its thermal stability.

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PO152

Investigation of polymer melt flow processes in the dosing zone of a plasticizing extruder and forming tool for various rheological models

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Today, polymeric compositions based on polyethylene and PVC are widely used as insulating materials. When choosing a rational mode of processing these materials, a number of problems, associated with the occurrence of local overheating are arise. At the same time, for some materials, exceeding the permissible temperature by several degrees leads to thermal destruction and, as a result, to a significant reduction in the mechanical and electrical properties of the finished product. In this paper, a three-dimensional model of the flow and heat transfer processes in the dosing zone of a plasticizing extruder, an adapter and a forming tool was developed. Also, spatial models with different channel geometries were considered: a rectangular channel, deployed on a plane; screw channel without gap above the crest of the screw; and a screw channel with a gap (a model, that is as close as possible to the real processing conditions). Experimental dependences of viscosity on shear rate have been obtained and empirical coefficients for three rheological laws have been determined: the power law, the Kerry model and the Cross model. The results of the calculation for the investigated rheological models under conditions of a complex shear in the screw channel of the extruder were compared. As a result of the study, the distributions of temperature, viscosity, shear rates and pressures were obtained for each spatial model. The influence of the output adapter and forming tool on the flow and heat transfer processes in the extruder channel was evaluated. The pressure-expenditure characteristic is constructed and the rational operating mode of the extrusion equipment is determined.

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PO153

Mathematical modeling of coextrusion of crosslinked polyethylene melts in cable heads

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Today the process of coextrusion is the most technological in the cable production with cross-linked polyethylenes, composed of two or more layers of polymeric insulation. In case of development of mathematical models of the process of coextrusion of polymeric materials in the forming tool channel, necessary to set the rheological characteristics of the materials investigated. The cross-linking of the grafted material in this case take place directly in the coextrusion process, and sometimes it is impossible to determine the rheological parameters when examining samples of finished products under laboratory conditions. The experiments have been performed for the three extruders used for the simultaneous creation of three-layered cable insulation. As a result of the experiment were obtained by the value of the pressure in the channels, temperature, time and mass of the materials, used the last to determine the flow rate of materials for the three extruders. The experimental results were taken as input for mathematical modeling processes of flow and heat transfer in the channels investigated extruders. During the numerical research have been defined rheological characteristics that are included in the power law, and the temperature coefficient. The second part of this study was devoted to determining the influence of the geometric parameters of a forming tool on the characteristics of the stratified flow of non-Newtonian liquids. As a result numerical simulations were obtained field pressures, velocities and temperatures in the channels of cable head.

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PO154

The role of the topological constraints in the chain dynamics in all-polymer nanocompositesPetra Bacova¹, Federica Lo Verso², Arantxa Arbe³, Juan Colmenero⁴, Jose A. Pomposo⁵, and Angel J. Moreno³¹*Institute of Applied and Computational Mathematics, Foundation for Research and Technology-Hellas, Heraklion, Greece;* ²*Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, Odense 4230, Denmark;* ³*Centro de Fisica de Materiales CSIC-UPV-EHU, San Sebastian 20018, Spain;* ⁴*Departamento de Fisica de Materiales, Universidad del Pais Vasco UPV-EHU, San Sebastian 20018, Spain;* ⁵*IKERBASQUE Basque Foundation for Science, Bilbao 48013, Spain*

In an effort to get a good compatibility between nanoparticles and polymer matrix, all-polymer nanocomposites are gaining increasing attention. In such systems the nanoparticles have no hard components but are fully polymeric objects. An example of these soft nanoparticles are the so-called single-chain nanoparticles (SCNPs), which are prepared from linear precursors through purely intramolecular cross-linking. By means of large-scale simulations, we investigate nanocomposites formed by linear chains and SCNPs. To distinguish the role of the soft penetrable character of the SCNPs in the topological constraints from other specific contributions present in experiments, the simulations for different compositions are performed at constant density and with identical segmental mobility and monomer excluded volume for SCNPs and chains. All compositions lead to well-dispersed nanocomposites with fully penetrated SCNPs. Hence, unlike in the case of hard nanofillers, the SCNPs do not exert confinement effects on the linear chains and only contribute to the topological constraints. We discuss the dynamics of the linear chains in terms of the tube model. We determine the entanglement length of the linear chains by analyzing their isoconfigurational mean paths (IMP) and primitive paths (PP). We use different estimators proposed in the literature. The IMP and PP analysis in the nanocomposites with sparse SCNPs yields values of the entanglement length smaller and larger, respectively, than in the reference pure linear melt, though small variations are observed. A more consistent trend is found in the nanocomposites with globular SCNPs, where both the IMP and PP analysis unambiguously reveal that the linear chains are more entangled than in the pure linear melt. Such differences between the effects of SCNPs with different topologies are presumably related to the much higher fraction of threadable loops in the globular SCNPs, with respect to the sparse case, which effectively lead to more topological constraints.

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PO155

Printability evaluation through fluid dynamic considerations of gravure inks for high performance organic thin film transistorsSabrina Calvi¹, Francesco Maita¹, Matteo Rapisarda¹, Guglielmo Fortunato¹, Antonio Valletta¹, Valentina Preziosi², Antonio Cassinese³, Stefano Guido², and Luigi Mariucci¹¹*CNR-IMM, Rome, Italy;* ²*Department of Chemical, Materials and Production Engineering, Università degli Studi di Napoli Federico II, Naples 80125, Italy* ³*CNR-SPIN and Physics Dep., Univ. Federico II, P.le Tecchio 8, Naples 80125, Italy*

Organic materials offer several interesting features as regards to low-cost flexible electronics. Thanks to their solubility, elasticity and low thermal budget, they are suitable to develop inks for several printing techniques. Among these, attention has grown around roll to roll systems, such as gravure printing, as they allow to achieve high throughput, highly resolved and uniform thin layers. In this work we will show the improvement in ink printability obtained through the study of the materials fluid dynamic features. With regard to our modified gravure printer, we have evaluated several formulations of a conductive polymer used for transistor electrodes, based on PEDOT:PSS, and of a fluoropolymer based dielectric. Numerical fluid dynamic and rheological analyses have been performed on the inks, the results obtained have been validated through the comparison with the outcomes of the printing tests. The rheological analyses have allowed us to deeply understand the fluid dynamic characteristics of the inks. In particular, we have investigated possible instabilities in the inks as a function of the shear rate applied during the printing process and evaluated the material elastic features and yield point. The printing parameters, the wettability differences, the cell shape and pattern have been accurately fitted on the fluid properties exploiting the results of such study. Afterwards, the assessment of the electrical performance of the inks have been carried on realizing fully printed multi-fingered organic thin film transistors with staggered top-gate configuration, on flexible polyethylene-naphthalate (PEN) substrates (100 μm thick).

Wednesday 18:10 Foyer Sirene

PO156

Second Newtonian branch of xanthan solutionsHaider Dakhil and Andreas Wierschem*Lehrstuhl für Strömungsmechanik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen 91058, Germany*

We study aqueous xanthan solutions with a narrow-gap rheometer [1] at gap widths of 20 μm and shear rates up to 10^5 s^{-1} . The gap-width precision is better than $\pm 1 \mu\text{m}$. At these shear rates, salt-free solutions show a second Newtonian branch. Depending on the xanthan concentration, we find two different regimes that we identify by their scaling laws. Up to a concentration of 0.2 wt.%, we find a linear dependence of the specific viscosity in the second Newtonian branch. Beyond that concentration, the specific viscosity is approximately proportional to the square root of the concentration. We also measure the normal-stress differences and discuss their implications at the high shear rates studied.

[1] Dakhil, H. & Wierschem, A. (2014). Applied Rheology, 24(6), 63795-63801.

Wednesday 18:10 Foyer Sirene

PO157

Experimental and modeling study of the dispersion of polyolefin elastomer in a low-viscosity polypropylene

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Controlling the dispersion of polyolefin elastomers in polypropylene is critical for applications requiring low temperature impact toughness, such as automotive TPO compounds or refrigerator boxes. To better understand the role of polyolefin elastomer design and rheology on dispersion in polypropylene resins, experiments were conducted with blends of commercial polymers at application-relevant blend ratios in simple flow fields. More specifically, polyolefin elastomers with different rheological properties were blended in a low-viscosity polypropylene matrix. The high viscosity ratio of such blends makes it challenging to reach a fine dispersion. In parallel, a computational fluid dynamics model was developed to study the effect of viscoelastic behavior on particle break-up in similar model flow fields. Results of experimental and modeling studies were compared and the utility of the computational fluid dynamics model to help with polyolefin elastomer design was demonstrated.

Wednesday 18:10 Foyer Sirene

PO158

Viscoelastic properties of entangled linear chains containing threaded macrocycles

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In this work, we study the viscoelastic properties of entangled linear chains threaded into the cavity of macrocycles. To this end, a step by step synthesis protocol is followed in order to incorporate macrocycles (rings) along copolymers of linear poly(ethylene glycol) containing bulky end-groups in order to prevent the rings from unthreading. The viscoelastic properties of the samples obtained at each stage are then determined and analyzed with the help of the TMA tube model, in order to understand the role of the different components (chain extender, bulky end groups, rings etc) on the dynamics of the chains. We also study the influence of the ring mobility along the chain, by comparing systems where the rings are fixed and where the rings can slide along the chains. Starting from the experimental results, we then modify the tube model for linear entangled polymers in order to account for the influence of ring mobility, and possible ring associations on the dynamics of these systems. Our final goal is to synthesize, characterize and model the viscoelastic behavior of well-defined slide-ring gels with controlled mobility of the rings.

Wednesday 18:10 Foyer Sirene

PO159

Functional materials for structural applications: preparation and rheological properties

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In recent years polymer composites are increasingly used in structural applications, ranging from civil infrastructure to high performance vehicles such as racing cars and military aircraft. This is due to their lower weight, as well as to a continuous improvement of their performance driven by nanotechnology. Indeed the nano-incorporation of fillers into polymeric matrices can impart new and exciting properties not obtainable by the single materials. The specific mechanical properties of the composite can be even utilized to improve the structural efficiency over conventional metallic structures. However, problems can arise for the effects of impact damage on the structural integrity of the material. Impact damage may lead to substantial matrix microcracking and delamination within the bulk of the composite, reducing the structural capability and leading to premature failure, if the damage is not detected and repaired. Damage can also provide a route for the ingress of contaminants into the structure. The internal damage is difficult to detect and even more difficult to repair and, once it has developed, the integrity of the structure is greatly compromised. The potential application of composite materials in aeronautics can be extended with the integration of specific functions in the structure of the material to make it more resistant to the previously mentioned adverse factors. In this paper, the design of a new generation of self-healing structural materials is proposed. Toughened nano-modified epoxy resins using MWCNTs and fillers derived from barbituric acids have been investigated. Aspects related to the manufacturing process have been analyzed. Rheological measurements in the liquid state, before curing, were carried out on a Physica-MCR301 (Anton-Paar) rotational rheometer. Small amplitude oscillatory shear measurements were performed at different temperatures. The rheological properties have been studied in the view to apply these new self-healing systems in primary aeronautical structures.

Wednesday 18:10 Foyer Sirene

PO160

Toughening of polyolefin recycled blends without sacrificing stiffness and strength by melt blending with polyamide nanocomposites

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The principal aim of this study was the upgrading of mixed polyolefin wastes through the addition of a sepiolite clay to obtain recycled products with improved properties. Moreover, a virgin polyamide and its nanocomposites with sepiolite, were also added to the recycled material in order to combine the advantages of the addition of a high performance plastic and the merits of polymer nanocomposites, also taking benefit of the function of nanofillers as potential blend compatibilizers. The recycled material, used as matrix, comes from flexible packaging wastes and it is mainly constituted of polyethylene and of a small fraction of polypropylene. This recycled polyolefin blend was melt compounded with an organo-sepiolite in a twin-screw extruder. Nanocomposite systems at several contents of sepiolite were also prepared by melt compounding, using as polymer matrix a copolyamide 6/66. Different amounts of both the neat polyamide and its nanocomposite at 20wt% of sepiolite were added to the recycled material in the twin screw extruder. The dynamic viscoelastic properties of the materials were measured using a rotational rheometer, meanwhile, a

capillary rheometer was used to investigate the processability. Ribbons of the neat matrix and the corresponding nanocomposites were produced by means of a single screw extruder and were submitted to thermal and mechanical characterization. The addition of both the neat polyamide and its nanocomposites to the recycled material determined interesting improvements in the mechanical properties of the post-consumer polyolefin blends. In particular, the recycled material with the lower content of copolyamide based nanocomposite showed a very remarkable enhancement of ductility without sacrificing stiffness and strength of the recycled matrix.

Wednesday 18:10 Foyer Sirene

PO161

Polyester/corn flour blends: Phase structure and rheological behavior

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Polymer blends based on synthetic biodegradable polyester and native corn flour were prepared in one processing step. During the processing, corn flour was plasticized by traditional plasticizers and new types of plasticizers derived from ionic liquids. Rheological properties were measured using rotational rheometry. Final phase structure of prepared blends was evaluated by scanning electron microscopy and wide-angle X-ray scattering. It is demonstrated, that the processing behavior and blend structure is predominantly controlled by blend composition and the quality of plasticized used.

Wednesday 18:10 Foyer Sirene

PO162

Effect of antioxidants in PP based polymer mixture on thermal degradation during its processing

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The effect of amount and type of antioxidants in the PP matrix on thermal degradation of the mixture during its processing has been investigated. The defined amount of each mixture was processed by using micro-compounder at the same temperature and speed. During the experiments, the decreasing force, characterizing the resistance of the melt against mixing, was recorded in time. Thus, the effect of stabilizers and their amount in the mixture can be observed to delay the thermal degradation process during their processing. Thermal stability increases with increasing amounts of stabilizers.

Wednesday 18:10 Foyer Sirene

PO163

Effect of rheological characteristics of polyethylene oxide on the electrospinning

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The effects of average molecular weight (MW) on the fibre diameter of electrospun polyethylene oxide (PEO) have been investigated. PEO with molecular weights ranging from 100 000 to 1 000 000 g/mol was dissolved in distilled water at various concentrations. The rheological properties especially the elasticity of polymer solution were measured and correlated with average fibre diameter. It was observed that the elasticity of PEO aqueous solutions increased with increasing MW whereas the viscosity was kept fixed. Nanofibrous webs obtained at optimal conditions were analysed by means of a scanning electron microscope. The diameter of fibres with circular cross sections increased with elasticity of polymer solution.

The authors wish to acknowledge GA CR for the financial support of Grant No. 17-26808S.

Wednesday 18:10 Foyer Sirene

PO164

The interrelation between rheology and spinnability of poly(ethylene oxide) dissolved in poor and good solvents

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Applying rheological characterization of poly(ethylene oxide) solved in good and poor solvents the overlap concentrations were approximated. It was proved for poor solvents that these concentrations are related to quality of electrospun fibres, it means whether the obtained nanofibrous mats are uniformly distributed or not. Therefore, for qualitatively acceptable distribution of nanofibres it is necessary to exceed an overlap concentration for poor solvents. It was shown that for good solvents this criterion fails and no acceptable nanofibrous web is possible to expect even for concentration exceeding an overlap concentration.

The authors wish to acknowledge GA CR for the financial support of Grant No. 17-26808S.

Wednesday 18:10 Foyer Sirene

PO165

Biopolymer based stimuli-responsive soft composites

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We fabricate two soft composites systems using biopolymer networks of fibrin and stimuli-responsive particles: micron sized magnetically active iron particles and highly swollen temperature-responsive pNIPAM microgels. Both the composites exhibit drastic increase in the mechanical properties under the application of external stimulus. In the case of iron-fibrin composites, even

at a very modest volume fraction of particles (0.3% v/v), the sensitivity of the shear moduli to the magnetic field surpasses the previously reported sensitivity in typical magnetoelastomers or magnetohydrogels. The viscoelastic moduli show a 30 fold increase. In the pNIPAM-fibrin composites, contrary to the softening response of individual components, the composites stiffen with increasing temperature, with a 10 fold increase in the viscoelastic moduli. We hypothesize this stiffening response arises from two underlying mechanisms: interparticle and particle-polymer interactions. Unlike the traditional soft composite systems, where the interparticle interactions tune the mechanics of the composites, we hypothesize that the particle-polymer interactions contribute significantly in our case. We hypothesize that the interaction between the magnetic particles induce local stress in the fibrin mesh, which inherently stiffens under the stress owing to its semi-flexible nature. In the case of pNIPAM-fibrin system, the pNIPAM microgels collapse/expand with temperature and stretch the attached fibrin mesh, thus inducing a stiffening response from the fibrin mesh. We utilize microscopic techniques to visualize the composite microstructure and build physical models to augment our understanding of the mechanics. Our approach of using composites based on semiflexible polymers with strong inherent nonlinearity offers a promising method for developing functional materials requiring controllable material properties.

Wednesday 18:10 Foyer Sirene

PO166

Parallel superposition of welan gum solutions

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A study of rheological properties of welan solutions was carried out in terms of polymer concentration (0.2 to 2.5 % m/m) at 20°C. The flow behaviour was determined by combination of step-wise flow curves and creep tests. The results showed shear thinning behaviour which fitted fairly well the Carreau model" ($R^2 > 0.99$). The zero-shear viscosity and the slope of the power-law region increased with welan gum concentration, as a consequence of increasing number of transient junction zones. Parallel superposition tests were conducted at different steady shear stress values. This test allows the influence of steady shear over the viscoelastic properties to be captured. All samples showed weak-gel like behaviour in the zero-shear Newtonian plateau and their parallel viscoelastic modules did not change with the applied stress. However when the applied stress exceeded the Newtonian plateau, a crossover between parallel viscoelastic modules was observed. The terminal relaxation time calculated from the crossover frequency decreased with welan concentration. On the other hand, it increased with the parallel shear stress as the macromolecular network was progressively weakened.

Wednesday 18:10 Foyer Sirene

PO167

Rheological responses of vulcanized rubbers to non-sinusoidal deformations displaying linear-nonlinear dichotomy feature

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We investigated rheological responses of carbon black filled vulcanized SBR elastomers under oscillatory shear conditions that are non-sinusoidal. For this purpose, we designed four test protocols of deformations that included sinusoidal wave, triangular wave, logarithmic wave and exponential wave. We found that particle-filled rubbers display an anomalous linear-nonlinear dichotomy in stress responses in all types deformations in nonlinear regime. Specifically, the Lissajous plots of stress-strain data from all test protocols are nearly elliptical and overlapping each other though the amplitude of stress deviates strongly from the linear dependence of strain. This stunning result suggests that the linear-nonlinear dichotomy of rheological responses of particle-filled rubbers is not particularly sensitive to the deformation wave selected during cyclic deformations [1].

[1] Xiong, W. & Wang, X. (2018). Journal of Rheology, 62(1), 171-181.

Wednesday 18:10 Foyer Sirene

PO168

Hydration behavior and rheology of chemically modified celluloses

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In this study, we report the temperature T dependencies of the hydration numbers for methyl cellulose(MC) and hydroxypropylmethyl cellulose(HPMC) samples by using dielectric relaxation measurements. Additionally, we investigated the T dependence of dynamic viscoelastic behavior, in order to understand the mechanism of gelation for chemically modified cellulose in aqueous solution. MC and HPMC were coded as MC(m:Mw / 1000) and HPMC(hp:m:Mw / 1000) with numerical quantities, m, hp and Mw, which represent the degree of substitution of the three hydroxyl groups per glucopyranose unit by methyl groups, the molar substitution by hydroxypropyl groups, and the weight-average molar mass, respectively. Dielectric spectra for the aqueous solution of MC and HPMC were well described with the summation of three kinds of Debye-type relaxations (mode 1 to 3 from the fastest relaxation mode). The fastest relaxation mode 1 assigned to free water in aqueous solution. [Hydration Number] The concentration c dependencies of relaxation strength, ϵ_1 allows us to determine the hydration numbers, nH, per glucopyranose unit. T dependencies of nH for MC(1.8:95) and HPMC(0.15:1.8:75) were investigated. The nH values decreased with increasing temperature. As the molar substitution by hydroxypropyl groups increased slightly from 0 to 0.15, the dehydration behavior with increasing T becomes dull. To fall nH below 5, aqueous solutions of MC and HPMC show clouding points. [Dynamic Viscoelastic Behavior] Although most of the polymer chains behaved as free chains in a low temperature range, a small part of them formed a weak network structure possessing a long relaxation time. The amount of network forming polymer chains increased with increasing T due to the dehydration behavior, and the fully grown network finally caused gelation.

Wednesday 18:10 Foyer Sirene

PO169

Rheological symptoms of long-chain branching in very low molecular weight polyethylenes irradiated by electron beam at relatively low doses

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Dynamic and transient shear and elongation flow experiments along with gel permeation chromatography (GPC) are performed on very low molecular weight polyethylene irradiated at doses below 40 kGy. Dynamic shear rheological behavior including thermorheological complexity, type of reduced van Gurp-Palmen curves, and zero shear-rate viscosities all disclose growing levels of long-chain branching with irradiation dose. Results reveal progressive increase in the length and fraction of long-chain branch chains, as evidenced by appearance of an anomalous double overshoot in the transient shear viscosities. Detection of strain hardening in extensional stress growth coefficient data, well-quantified by molecular stress function model.

Wednesday 18:10 Foyer Sirene

PO170

Interphase transfer of plasticizer in immiscible polymer pair

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Interphase transfer of di-butyl phthalate (DBP) between poly(lactic acid) (PLA) and ethylene-co-vinyl acetate (EVA) was studied using the laminated sheets in which each sheet contains 10 phr of DBP. It was found that the DBP transfer occurs during annealing beyond their glass transition temperatures. The transfer direction and its amount were dependent upon the annealing temperature. This is attributed to the temperature dependence of the difference in the interaction parameter between each polymer and DBP. The phenomenon could be applicable to a damping material showing high loss tangent in a wide temperature range.

Wednesday 18:10 Foyer Sirene

PO171

Viscosity drop and segregation behavior of polycarbonate/poly(methyl methacrylate) blend

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Viscosity drop phenomenon of polycarbonate (PC) by addition of low-molecular-weight poly(methyl methacrylate) (PMMA) was confirmed by the study using a capillary rheometer. Furthermore, PMMA segregates onto the surface of an extruded strand or injection-molded plate, which was investigated by attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR). The enrichment of the PMMA fraction on the surface was also responsible for the surface hardness, which is always required to be improved for PC.

Wednesday 18:10 Foyer Sirene

PO172

Effect of glass transition on the texture properties of dry food products

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Dried food products are commonly in an amorphous state, and amorphous solids suddenly undergo evident rheological changes at a glass transition temperature (T_g). In order to control and predict the physical properties (e.g., texture) of dry food products, it is practically important to understand their T_g . Differential scanning calorimetry (DSC) has been widely used to determine T_g of amorphous materials. However, it is commonly difficult to detect T_g of dry food products, because not only multiple thermal responses, but also small and broad endothermic shift are observed. In such cases, thermomechanical approaches are effective for the determination of T_g . In our research group, thermal rheological analysis (TRA), which is essentially equivalent to thermal mechanical analysis, was conducted. The purpose of this study was to understand effect of water content on the mechanical T_g and texture change of dry food products. Commercially available plain cookie and deep-fried crumbs were purchased in a local market. The samples were equilibrated in various relative humidity (RH) conditions, and their water content was examined gravimetrically. Mechanical T_g of the samples was evaluated by the TRA. For comparison, DSC measurement was also carried out. Texture properties were investigated by a texture analyzer. DSC curve showed a complicated thermal response owing to the melting of the fat present in the sample, and thus it was difficult to determine the T_g from the DSC measurement alone. The TRA curves, on the other hand, showed a clear force drop, allowing the mechanical T_g to be determined. The mechanical T_g decreased with an increase in water content because of water plasticizing effect. From the T_g -depression behavior, critical water content (water content at $T_g=25^\circ\text{C}$) was evaluated. Fracture properties of the samples changed discontinuously (brittle or ductile) at the critical water content.

Wednesday 18:10 Foyer Sirene

PO173

Analysis of intrinsic-nonlinear measures of PS solutions in medium amplitude oscillatory shear (MAOS) regime

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The intrinsic-nonlinear responses of model polystyrene solutions were investigated under medium amplitude oscillatory shear (MAOS) using Fourier-transform rheology. Because intrinsic nonlinearity Q_0 combines its elastic and viscous parts and loses sign information, we here calculated decomposed Q_0 values, called elastic Q_0 and viscous Q_0 (Q_0' and Q_0''). Furthermore, intrinsic-nonlinear $\tan \delta$ ($\tan \delta_{3,0}$) was calculated as the ratio of Q_0'' to Q_0' . Using arbitrary equation tests and phase angle information, physical meanings of Q_0' and Q_0'' were determined. All intrinsic-nonlinear master curves of model solutions showed the typical terminal

behaviors. Unentangled solutions had the same intrinsic nonlinearities at the same De . The intrinsic-nonlinear master curves of entangled solutions superimposed near terminal regime but deviated at high De due to different entanglement states of each solution. Therefore, two characteristic times, MAOS time and inflection time (τ_N and τ_{inf}), were determined from intrinsic-nonlinear master curves by comparing with terminal relaxation time and Rouse time. These results show that intrinsic nonlinearities from MAOS methodology are sensitive to relaxation processes of polymer chains. Lastly, the obtained master curves were compared with molecular stress function (MSF) model and pom-pom model. The single-mode predictions of two models described behavior changes qualitatively. However, both failed to achieve quantitative predictions. On the other hand, the multimode version of MSF model agreed well with experimental data from terminal regime to inflection time scale under terminal relaxation mode assumption.

Wednesday 18:10 Foyer Sirene

PO174

Phase state and rheology of linear polymers blended with silicone resins

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Silicone resins are hyperbranched macromolecules with nearly spherical shape, nanometer sizes, and a lot of terminal groups. For this reasons they can act as analogues of functionalized silica nanoparticles that are soluble in a polymer medium. In our research, mixtures of linear polymers (polyisobutylene and polydimethylsiloxane) with methyl- and dimethyldecylsilyloxy-terminated silicone resins were considered. For blends with different molecular weights of the resins, the phase diagrams were obtained by laser interferometry and their rheology was studied in detail. The effect of terminal groups of the resins, their molecular weight and the nature of the linear polymer on miscibility was demonstrated. The methyl-terminated MT resins are well miscible with PDMS, whereas their solubility in PIB even at high temperatures does not exceed a few percent. For the dimethyldecylsilyloxy-terminated MDT resins, the situation was reversed: they were better soluble in PIB, but worse in PDMS. The rheology of the blends was determined by their phase state, which depended on the nature and the ratio of the components, and also on the temperature. For homogeneous resin/PDMS mixtures, a slight positive viscosity deviation from the log-additivity rule is characteristic, whereas heterogeneous concentrated resin/PDMS blends (which are formed with the highest molecular weight resin at normal temperature) are similar in rheological properties to vulcanized rubbers. Conversely, the resins significantly reduce the effective viscosity of PIB due to their partial solubility in its medium and to the shear-induced interlayer slip. This research was supported by the Council for Grants of the President of the Russian Federation (project No. MK-545.2017.3). The authors are grateful to academician A.M. Muzafarov (N.S. Enikolopov Institute of Synthetic Polymeric Materials) for the silicone resins provided for the study.

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