DEVELOPMENT OF BIOCATALYTIC MEMBRANE CONTACTOR USING RUBISCO AS NATURE-INSPIRED ALTERNATIVE PATHWAY FOR CO2 CAPTURE AND CONVERSION

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Abstract

A biocatalytic membrane for CO_2 capture and its conversion into organic compound was synthesized using Nature's most abundant enzyme, Ribulose-1,5-Biphosphate Carboxylase/Oxygenase (RuBisCO), as a benign biocatalyst. RuBisCO was covalently immobilized on commercial flat-sheet porous polymeric membranes to improve its stability. Dopamine and polyethyleneimine were used to modify the membrane surfaces for improved enzyme compatibility, while glutaraldehyde was used as the crosslinker for immobilization. Results showed that the use of polyvinylidene fluoride (PVDF) led to higher surface amino density and higher enzyme retention compared to polypropylene (PP). However, increasing the coating duration did not necessarily led to increased enzyme retention despite the increase in surface amino density, which could be attributed to stearic hindrance. Optimization of RuBisCO activity as a function of different immobilization parameters such as coating duration, glutaraldehyde concentration, enzyme concentration, pH, incubation temperature, and enzyme immobilization duration will be made. Finally, the stability, reusability, CO_2 capture and conversion performance of the optimized membrane will be evaluated. With this study, preliminary steps are taken in exploring the potential of biocatalytic membrane contactors for CO_2 capture and conversion into organic compounds.

Background

The goal of net-zero emission by 2050 is a challenging undertaking which requires implementation of numerous strategies to be successful [1]. These strategies aim to phase out the use of fossil fuels which is currently the main carbon source (85%) for the synthesis of important chemicals such as organic compounds [2]. This means that alternative carbon sources must be developed to support the net-zero emission goal. Post-combustion CO_2 presents as an attractive alternative carbon source as it is renewable and a waste product. However, the high stability of CO_2 necessitates extreme conditions for its practical conversion into useful chemicals. Fortunately, the conversion of CO_2 into organic compounds has been widely practiced in Nature through photosynthesis. An enzyme, called RuBisCO, catalyzes CO_2 capture from air and its conversion into an organic acid, called 3-phosphoglyceric acid (3-PGA), under ambient conditions [3]. In turn, 3-PGA can be used to produce key industrial organic intermediates such as glucose and pyruvate [4]. However, the instability of enzymes under in-vitro conditions has greatly hindered their application [5]. Therefore, this study proposes to immobilize RuBisCO on commercial flat-sheet porous polymeric membranes to improve its stability in vitro. The developed membrane can then be applied in a membrane contactor configuration for simultaneous CO_2 capture and product separation at process-level. This will be the first attempt in immobilizing RuBisCO on membrane contactors for industrial CO_2 capture and conversion prospects.

Current results

The biocatalytic membrane was developed by immobilizing RuBisCO on two commercial hydrophobic membranes, PVDF and PP (Figure 1). Briefly, one-side of the membranes was immersed in an equal mixture of dopamine and polyethyleneimine to functionalize the surface with the necessary amino groups for enzyme immobilization. The coated membranes were then immersed in a solution containing glutaraldehyde and RuBisCO to achieve covalent enzyme immobilization on the surface. The effect of membrane composition on enzyme immobilization was studied by comparing the coating properties and enzyme retention between PVDF and PP. Better coating was attained with PVDF compared to PP as shown by its lower water contact angle (Figure 2 (a)), and higher surface amino density (Figure 2 (b, bar graph)). The presence of more amino groups on PVDF resulted to more binding sites for glutaraldehyde resulting to higher enzyme retention than PP (Figure 2 (b, line graph)). On the other hand, increasing the coating duration of the PVDF membrane resulted to thicker coating (Figure 3 (a)) and increased surface amino density (Figure 3 (b, bar graph)), but not necessarily an increase in enzyme retention (Figure 3 (b, line graph)), which could be due to stearic hindrance.

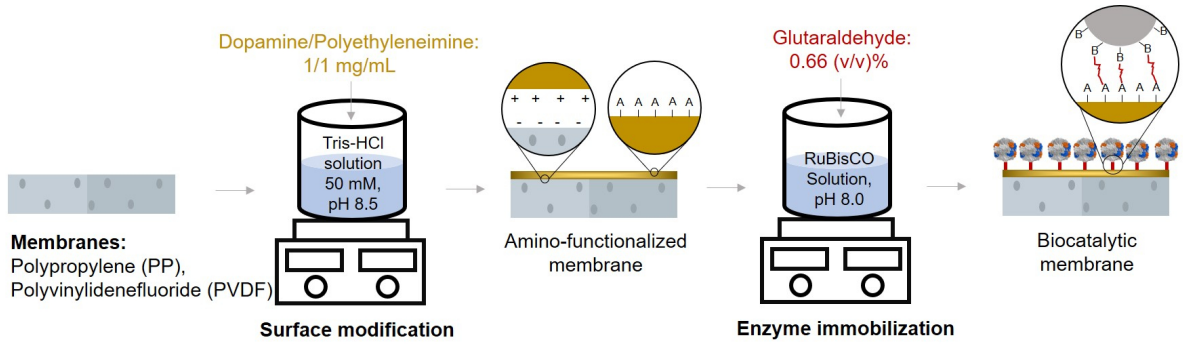

Figure 1. Biocatalytic membrane is prepared by first functionalizing the surface with amino-groups and then immobilizing RuBisCO.

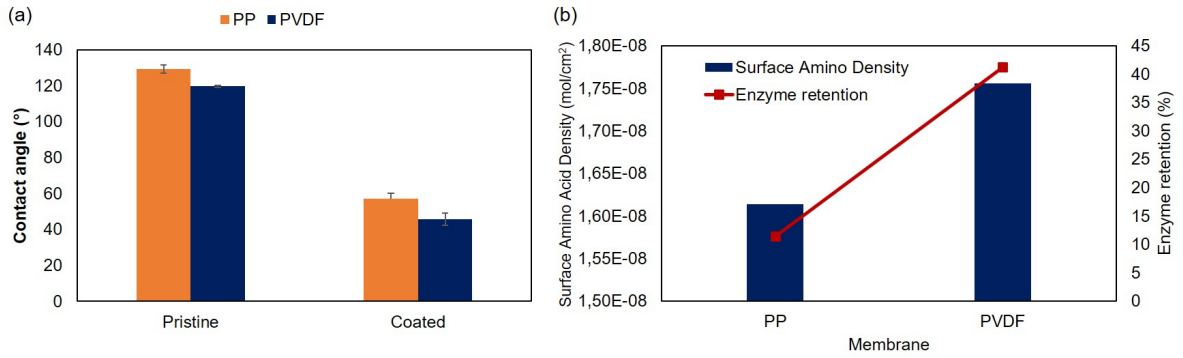

Figure 2. PVDF resulted better coating properties as supported by its lower water contact angle test (a) and higher surface amino density (b, bar graph), resulting to higher enzyme retention (b, line graph) compared to PP membrane.

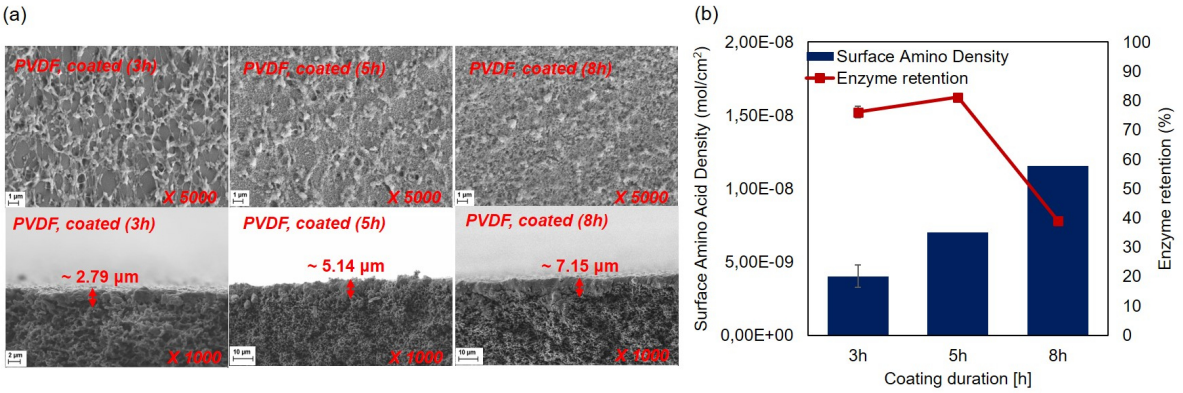

Figure 3. Increasing coating duration on PVDF membrane resulted to thicker coating (a) and higher surface amino density (b, bar graph), but the enzyme retention did not necessarily increase with coating duration (b, line graph).

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