Process intensification of alkaline water electrolysis using forced electrolyte flow through 3D electrodes (5)

Quentin de Radigues*, Thomas Dalne and Joris Proost

Institute of Mechanics, Materials and Civil Engineering (iMMC),
Université catholique de Louvain,
B-1348, Louvain-la-Neuve, Belgium

(*) quentin.deradigues@uclouvain.be

Summary

This presentation will show that the combination of 3-D electrodes, both 3D cathodes and 3D anodes, with a forced electrolyte flow can provide the much needed process intensification for alkaline water electrolysis. Results have been obtained at the labo-scale and using a full pilot plant set-up.

Introduction

Renewable energies such as solar and wind are by nature intermittent. To increase their use, the produced electricity needs to be stored e.g. under the form of hydrogen. In order to be industrially relevant and competitive, the electrochemical process used for hydrogen production needs to be intensified, i.e. increased production rate and/or decreased unit size. Water electrolysis also needs to be scaled-up to match the size of the most recent wind turbines.

In this presentation, we propose to achieve the necessary process intensification by combining two technologies: 3-D electrodes and forced electrolyte flow. The first will allow increasing the active electrode area per unit cell volume. The latter will impeach the produced gas bubbles to block the 3-D structure, which is typically the case when operating under natural convection. In the last part of this presentation, we will show the results of our technology scaled-up on an 18kW pilot plant.

3-D electrodes and forced flow

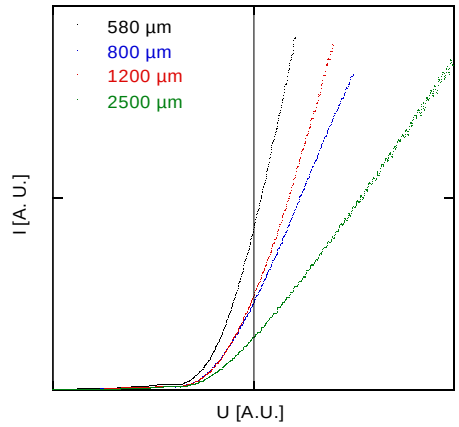

Figure 1. Current vs applied cell potential for various 3D electrodes (both anode-A and cathode-C) (Re: 580µm A= 570, C= 780; 800µm A= 500, C= 580; 1200µm A= 600, C= 520; 2500µm A= 620, C= 820)

Figure 1 shows the current vs applied cell potential obtained for various porosities of 3-D electrodes. The same porosity has always been used for both the anode and cathode compartment of the cell. Electrolyte flow rate is indicated using the Reynolds number (Re) with the hydraulic diameter of the cross section of the cell as characteristic length. One can clearly see on Figure 1 that, the smaller the pore size, the higher the obtained current for a same applied cell voltage. At the vertical line in Figure 1:

$$I_{580\mu m} > I_{800\mu m} > I_{1200\mu m} > I_{2500\mu m}$$

This is because 3-D structures develop a higher surface area per unit volume. A 3-D electrode with smaller pores will therefore have a higher active area than an electrode with bigger pores.

From the Butler-Volmer equation, we know that the overpotential of an electrochemical reaction increases with the current density.

$$j = j_0 \left[\exp\left(\frac{(1-\alpha_a)ZF}{RT}\eta\right) - \exp\left(-\frac{\alpha_c ZF}{RT}\eta\right)\right]$$

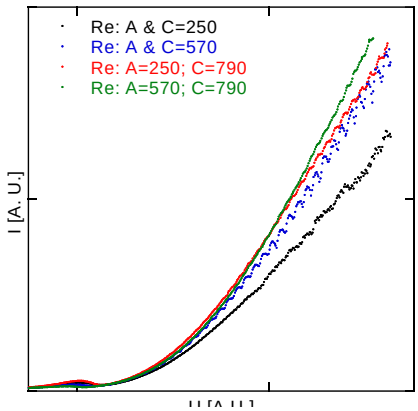

Figure 2. Current vs applied cell voltage for both 3D anode and cathodes of 580 µm pores at various forced flows.

As we increase the active surface of the electrode using 3-D electrodes with smaller pores, we decrease the current density for a same measured current. This smaller current density will in turn decrease the overpotential, which will result in lower cell voltage. Alternatively, as we put it in Figure 1, 3-D electrodes with smaller pores produce a higher current for the same applied cell voltage.

We have also studied the impact of forced flow. As we can see on Figure 2 increasing the flow from 250 Re (black dots) to 570 Re (blue dots) increases the obtained current for a same applied potential for about 35%. This is because the produced gas bubbles can block the 3-D structure at lower flow rates. When the structure is blocked its active surface area decreases, increasing the reaction over-potential as seen in the previous section. Increasing the forced flow forces the bubbles out of the 3-D electrode making its entire surface area active. Looking at Figure 2, we can also note that increasing the flow in the cathodic compartment of the cell (green and red dots) has a positive effect on the output current.

The impact of the flow in the anodic compartment is less marked. As we can see in Figure 2, we do have a positive effect of the anolyte flow when the catholyte flow is at its maximum (going from the red dots to the green ones). When the flow in the catholyte compartment is lowered and increased in the anolyte compartment, they seem to compensate (blue curve vs red curve in Figure 2).

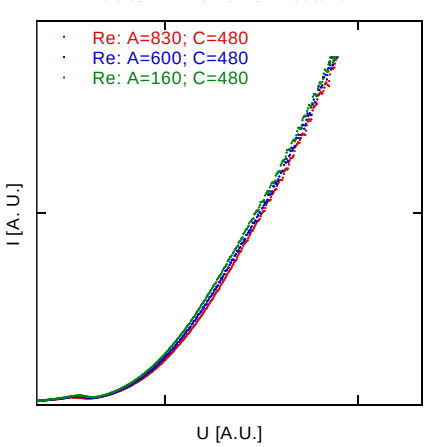

Figure 3. Current vs applied cell voltage for both 3D anode and cathodes of 1200 µm pores at various forced flows.

Figure 3 shows the effect of the anolyte flow on 3-D electrodes with larger pores. As we can see, no effect is observed when the catholyte flow is relatively high. This shows that the porosity of the 3D structure is an important parameter when one optimizes the forced flow in a cell. Electrodes with bigger pores depend less on the flow as the produced bubbles will escape more easily.

Observations made in Figure 2 and Figure 3 tend to show that in a cell using both 3-D cathodes and anodes under forced flow, one should maximize the catholyte flow. This has the most significant impact on the measured current. This is because the volume of produced gas on the cathode side is twice that on the anode (H_2O splitting produces twice more hydrogen as oxygen gas). Furthermore, the influence of flow is more important for 3-D electrodes with smaller pores. Using 3-D structures with bigger pores can therefore allow sparing on the pumping power. Then again, electrodes with smaller porosities allow reaching higher currents for a same applied potential.

Scale-up:

Our lab has recently acquired an 18kW pilot plant for alkaline water electrolysis. It has a cell stack of 24 cells of 300cm² projected surface area. This unique set-up will allow proving our technology at a scale relevant for industrial applications.