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Technical Electrochemistry Group I, lab A023

CHARACTERIZATION OF A PEM ELECTROLYZER

INTRODUCTION

Hydrogen, as a commodity chemical, is nowadays mainly produced from fossil fuels by steam reforming or partial oxidation. However, it is possible to produce hydrogen in a clean way using electricity and water. Industrially, there is an established method that uses potassium hydroxide electrolyte, from which hydrogen and oxygen is evolved upon passing an electrical current. A competing method using an acidic polymer electrolyte is emerging, called the PEM water electrolysis, the acronym PEM standing for polymer-electrolyte membrane. Although not implemented on an industrial scale, this method offers higher efficiency and higher process intensity, i.e., lower space demands. The reason why this method is not used industrially lies in its high investment costs and lifetime issues. Nevertheless, on a laboratory scale, there is a plethora of available devices, one of which you will test in this work.

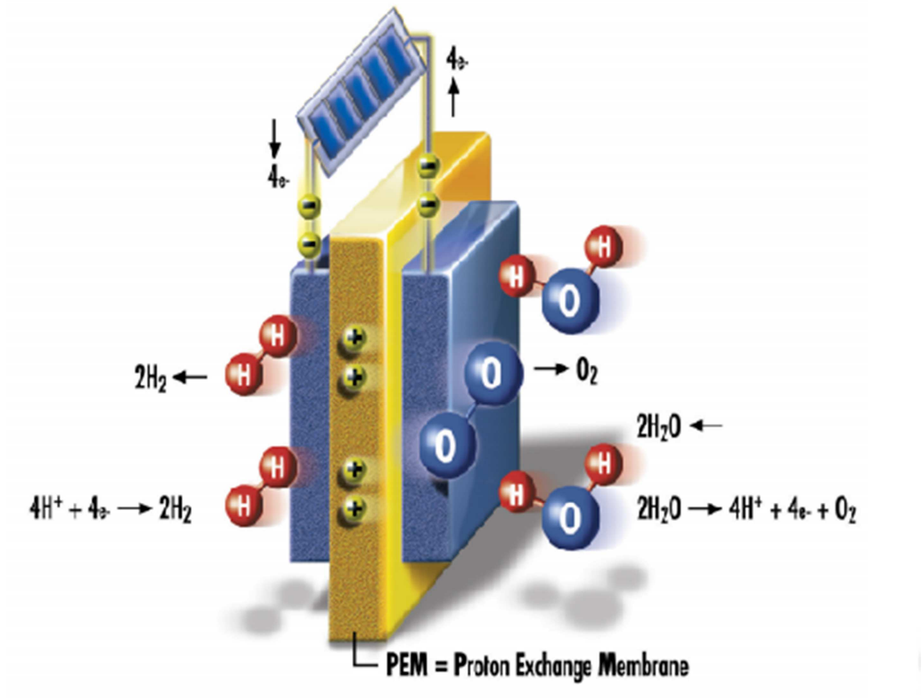

Fig. 1 Scheme of a PEM electrolyser.

THEORY OF OPERATION

PEM electrolysis is a complementary process to the PEM fuel cell. In a PEM electrolyzer – much like in a PEM fuel cell – a cathode and an anode are separated by a polymer-electrolyte membrane, which acts as a separator and a proton conductor. On the anode, water is oxidized to gaseous oxygen; the remaining proton is transported through the membrane to the cathode side where it is reduced to hydrogen gas – the product of interest. Electrochemical reactions are given below:

Anode:	$2H_2O => O_2 + 4H^+ + 4e^-$	$E^o_{red} = 1.23$ V	(1)
Cathode:	$4H^+ + 4e^- => 2H_2$	$E^o_{red} = 0.00$ V	(2)
Overall:	$2H_2O => O_2 + 2H_2$	$\Delta G^o_r = 474.2$ kJ/mol	(3)

CELL VOLTAGE

In thermodynamics, electromotive force (E) of a cell can be calculated from the cell reaction using formula (4), where z is the number of electrons exchanged in the reaction and F is the Faraday constant.

$$\Delta G = -zFE \tag{4}$$

In the water-electrolysis case, the electromotive force is negative, which means that we have to supply energy to the cell to make the water-splitting happen. The cell equilibrium voltage is simply an inverse (positive) value of the electromotive force.

THE EXPERIMENT

1) Assemble the apparatus: Connect the water inlet hose, oxygen outlet hose and hydrogen outlet hose.
2) Fill the tank with demineralized water and fill both burettes to the zero level.
3) Connect cables according to the schematic below.

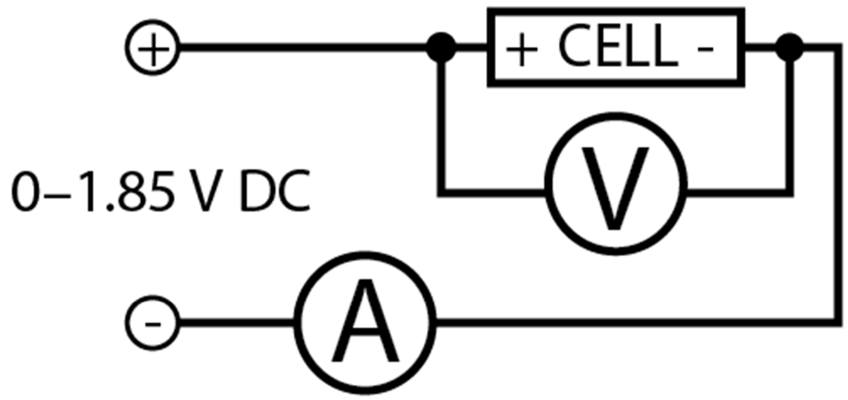

Fig. 2 Schematic of the electrical connection.

4) Set the cell current to 0.30, 0.50 and 0.70 A. Measure the cell voltage and time needed to produce 20 mL of hydrogen.Take note of the corresponding volume of evolved oxygen. Write down current and voltage at the beginning of the experiment and at the end of it. Use average values for calculations.
5) Set the cell voltage to 1.50, 1.55, 1.60, 1.65, 1.70, 1.75, 1.80 and 1.85 V respectively and measure the current.
6) After finishing the experiment, turn off the power supply, disconnect all cables and turn off the multimeters. Then, drain all the water from the setup and clean the workplace.

THE REPORT

For the report, write a concise introduction followed by experimental parameters so that anyone can reproduce your experiment. In the results, do the following:

1) Calculate the amount of hydrogen and oxygen that should have evolved from the point 4 (experiment) from the Faraday's law of electrolysis. Explain any observed differences.
2) Calculate the current efficiency (Faradaic efficiency) expressed as the amount of hydrogen actually evolved divided by the amount of hydrogen that should have evolved according to Faraday's law.
3) From the values from the point 5 (experiment) construct a graph showing cell voltage vs. current density. The electrode dimensions are 1×1 inch.
4) In the conclusions section, summarise the effect of current density on Faradaic efficiency and comment on the observed trend of growth of the current density vs. cell voltage.

HOME PREPARATION

Aside from reading the text above, answer these questions:

1) The electrolysis of water is thermodynamically an endothermic process. To make it thermally neutral, the remaining energy is usually supplied in a form of additional electricity. This can be expressed by a *thermoneutral* equilibrium water-splitting voltage calculated by substituting ΔG^{o}_{r} with ΔH^{o}_{r} in the equation (4). Calculate this voltage.
2) Because the kinetics of oxygen evolution during water-splitting is slow, we have to rise the voltage above the equilibrium voltage. The difference between the cell (applied) voltage and the equilibrium voltage is called an overpotential. From the values in point 5 (experiment) and thermoneutral equlibrium voltage, calculate the theoretical efficiency of the process. Efficiency is calculated by dividing the equilibrium voltage by the cell voltage and is always ≤ 1. Construct a graph or give a table with the values of efficiency vs. cell voltage.
3) One kWh of electricity costs approximately 5 CZK. Calculate the electricity price needed to produce one m^3 of hydrogen (25 °C, 100 kPa) at thermoneutral equilibrium voltage and at 1.80 V.