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Impact of the voltage fluctuation of the power supply on the efficiency of alkaline water electrolysis

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ABSTRACT

The efficiency of alkaline water electrolysis under DC conditions is largely dependent on the voltage fluctuation of the power supply. As a result of continuously varying voltage levels the electrode reactions are under dynamic influences, affecting cell performance and gas production. This effect was investigated by conducting a series of water splitting experiments where sinusoidal waves of increasing amplitude, frequency and offset was applied to a cell. Frequency ranged from 1 to 5000 Hz, signal amplitude was changed from 0 to 2 V, while the offset value (i.e. the DC component of the output signal) was varied between 1.4 V and 2.8 V. A fully automated, remote-controlled measurement system was designed, allowing for a large number of measurements. The used power supply can generate any type of waveform signal up to 50 kHz and ±10 V with a maximum current 8 A. By using a fluctuating DC power source H_2 flow rate and the power consumption of the electrolyser can be improved, but at the same time this may lead to a drop in overall efficiency. The details of the experimental system as well as the results of the experiments are presented here.

Introduction

Hydrogen is mostly produced from fossil resources, primarily from methane (natural gas) [1] due to cost-efficiency reasons. However, growing concerns about diminishing fossil fuel reserves and increasing gas prices drive attention to hydrogen production. The most common arguments against water decomposition using electrical power are of economic nature. Net efficiency of 56–73% is common with current electrolytic hydrogen production methods [1,2], however the overall efficiency is much lower if the losses of electricity generation from primary or renewable fuels are also taken into consideration. In this case the overall efficiency rate would hardly reach 25–40% [3]. The electrolytic process can be enhanced by manipulating external factors, i.e. by subjecting the cell to a super gravity field [4], to ultrasonic waves [5] or to permanent magnets [6]. If, on the other hand, a fluctuating DC source is applied instead of steady DC voltage, efficiency decline might occur in some cases.

The conventional DC electrolysis of water involves generation of hydrogen gas at the cathode and oxygen gas at the anode. The electrode reactions are typically described as follows [7]:

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cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

$2H^+ + 2e^- \rightarrow H_2$

anode: $2OH^- \rightarrow 0.5O_2 + H_2O + 2e^-$

$H_2O \rightarrow 0.5O_2 + 2e^- + 2H^+$

Gas formation can be induced by applying a potential difference between the cell electrodes. In theory, the thermodynamic decomposition voltage of water at 298 K and 1 atm is 1.23 V, however, due to reaction overpotentials and resistance losses (ohmic voltage drop), higher actual cell voltages should be applied [8]. Gas starts to form at a voltage level of 1.65–1.7 V and most industrial cells are operated from 1.8 to 2.6 V [8,9].

In order to create a potential difference between the electrodes AC/DC or DC/DC power supplies are typically used. One of the main properties of power supplies is the voltage ripple (noise), meaning that the voltage level as a function of time is not constant. Reduced or practically eliminated voltage ripple is an important requirement, although it is difficult to achieve with increased power. In water electrolysis any deviation from perfectly uniform DC voltage might affect the electric power consumption, the intensity of gas production and the efficiency of water splitting. This means, that using a power supply with a significant ripple can decrease the efficiency of the water electrolysis. Inversely, by smoothing the voltage fluctuation of the DC power supply the electrolysis efficiency can significantly increase. Although several papers were published on applying impulse voltage or interrupted direct current to the cell [10–13], according to some authors the available information about the effects of the applied voltage waveforms are relatively low [14,15]. In 2009 a group of scientists took an alternative approach, studying the influence of different types of power supply on the efficiency of alkaline water electrolysis [16]. It was shown, that the efficiency of water electrolysis can be changed by using different power supply topologies with different output voltage and current waveforms. The ripple of the available power supplies from 5 kW can reach 5–7% [17], in some cases it can even go up to 10% [18].

The main goal of this paper is to generate sinusoidal waveforms with various frequency, amplitude and offset values, and apply them to the electrolytic cell, modelling the ripple of power supplies. During the experiments cell voltage, cell current and the gas production were measured. Since the number of parametric combinations was obviously far too high to execute the experiments manually (within a realistic time scale), a special experimental system was set up, enabling fully automated control, measurement and data logging.

Measurement system setup

A schematic illustration of the measurement system is seen in Fig. 1. The central unit is the power supply, containing a high current operational amplifier OPA549 (manufactured by Texas Instruments) [19] controlled by National Instrument (NI)

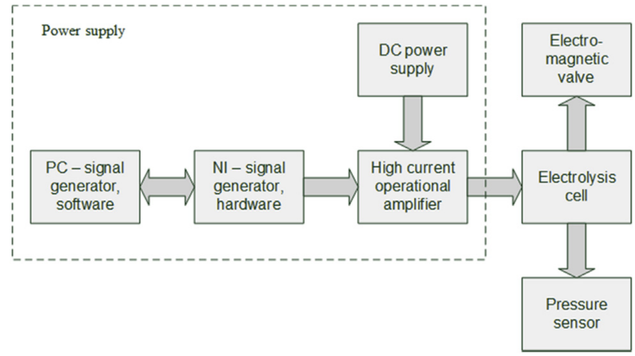

Fig. 1 – Schematic illustration of the measurement system.

Table 1 – Basic output parameters of the power supply.

Output parameter	Minimum value	Maximum value
Voltage, V	−10	+10
Electric current, A	0	8
Frequency, kHz	0	50

device type USB-6259. The NI device generates a signal programmed in LabVIEW software (National Instruments, 11.0 version, 2011). This system can generate any type of waveforms between the criteria showed in Table 1. The power supply can be operated either in galvanostatic or potentiostatic mode, i.e., it is able to generate voltage or current waveforms, according to the operational amplifier topology [19].

The power supply is connected to the electrolytic cell shown in Fig. 2. The cell is basically a gas-tight vessel with two electrodes attached to the lid. Next to the electrodes are two gas outlets, a T-type Thermocouple (used as a sensor to measure electrolyte temperature) and the outlet pipes of the cooling cycle (mounted on the lid). Two stainless steel electrodes (dimensions: 1.5 × 25 × 25 mm; material: EN 1.4307)

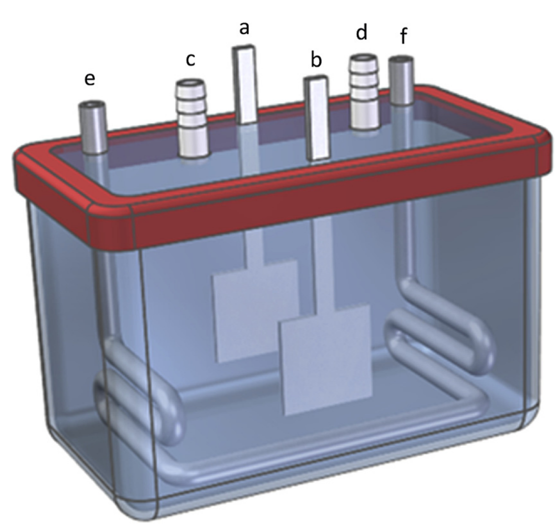

Fig. 2 – Schematic illustration of the electrolytic cell, a) cathode, b) anode, c) to pressure sensor, d) to valve, e) cooling water inlet, f) cooling water outlet.

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