Effect of Current Density, Temperature and Pressure on Proton Exchange Membrane Electrolyser Stack

Na Li, Samuel Simon Araya, Søren Knudsen Kær

***Abstract*—**This study investigates the effects of operating parameters of different current density, temperature and pressure on the performance of a proton exchange membrane (PEM) water electrolysis stack. A 7-cell PEM water electrolysis stack was assembled and tested under different operation modules. The voltage change and polarization curves under different test conditions, namely current density, temperature and pressure, were recorded. Results show that higher temperature has positive effect on overall stack performance, where temperature of 80 °C improved the cell performance greatly. However, the cathode pressure and current density has little effect on stack performance.

***Keywords*—**PEM electrolysis stack, current density, temperature, pressure.

I. Introduction

As the world's energy and environmental problems caused by the combustion of traditional fossil fuels are becoming more and more serious, the development of renewable energy has attracted more and more researchers' attention. Hydrogen, as a clean and efficient energy carrier, is considered to be one of the substitutes of the traditional fossil fuel. PEM water electrolysis is a clean and sustainable technology which decomposes water to generate hydrogen and oxygen by electricity. Compared to other electrolysis technologies, the advantages of higher gas purity, high efficiency and quick dynamic response etc. of PEM water electrolysis make it a promising technology to produce hydrogen.

Studies on the performance variation of PEM water electrolysis have been carried out. Many studies show that the performance of PEM water electrolyzer could be affected by many operation parameters such as current density, temperature and pressure etc. Chandesris et al. [1] developed a 1D model supported by specific single cell experiment to study the effect of current density and temperature on membrane degradation; results showed that high temperature significantly decreased the life time of the single cell and current density also have a complex influence on the single cell performance. Fouda-Onana et al. [2] carried out experimental work on single cells to investigate the effect of the current density and operating temperature on the membrane electrode assembly (MEA) performance and membrane aging of the tested cells. Result showed that high temperature has more severe effect on membrane degradation than current density. Lettenmeier et al. [3], using a commercial PEM electrolyser to test some rainbow stacks of which the MEAs came from different suppliers, proved that high current density (4 A/cm^2 for more than 750 h) did not lower the PEM WE performance but degraded the MEA. Grigoriev et al. [4] carried out an accelerated degradation test on a MEA by applying galvanostatic pulses and concluded that the anode side catalyst dissolution/ precipitation and membrane thinning are two main factors which affect the cell performance degradation. Saher et al. [5] investigated the effect of clamping pressure on single cell performance through an in-situ experimental work; results showed that that cell compression positively affected the overall cell performance.

As can be seen, most of these studies were carried out on single cells, studies on PEM water electrolyzer stack are scarce. However, the stacks are more commonly used in the practical application. Therefore, the performance investigation of PEM electrolysis stack is of great significance. In this study, a PEM water electrolysis stack of 7-cell was tested, and the effects of current density, temperature and pressure on the stack were investigated.

II. Experimental

The 7-cell stack used in this test is shown in Fig. 1. The membrane electrode assemblies (MEAs) used in this stack are round; the active area of each MEA is 69 cm^2 (radius of 4.69 cm). The MEAs are a sandwich structure which employed Nafion®115 membrane as the electrolyte, covered with 2.0 mg/cm^2 of IrO_2 on the anode side as the anode catalyst and 0.5 mg/cm^2 of Pt/C on cathode side as the cathode catalyst, respectively. The Ti felt with a thickness of 0.35 mm, fiber diameter of 20 μm and a porosity of 81% were used as the anode transport layer, a carbon cloth was used as the cathode side transport layer. Seven MEAs were compressed in series with the corresponding porous transport layers for each one, and then fixed together with current collectors and end plates on each side through screws and nuts to form the final tested 7-cell PEM water stack as shown in Fig. 1.

The PEM water electrolysis stack was tested on a Greenlight Innovation® water electrolyzer test station, where controlled of the test parameters, water flow rate, temperature, current density and pressure could be automated. The deionized (DI) water was fed to the anode and circulated between the anode side of the stack and the water supply system. The produced oxygen leaves the anode along with the circulating water and

Na Li is with Energy Technology Department, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg Øst, Denmark (corresponding author, phone: +45-9356-2455; e-mail: nal@et.aau.dk).

Samuel Simon Araya was with Energy Technology Department, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg Øst, Denmark (e-mail: ssa@et.aau.dk).

Søren Knudsen Kær is with Energy Technology Department, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg Øst, Denmark (e-mail: skk@et.aau.dk).

then is released into the air. The hydrogen produced on the cathode side is released to the fume hood.

The test was divided into four stages, the detailed test protocols are listed in Table I. As can be seen, the current density and operating temperature varied from stage 1 to stage 4, where the cathode pressure was kept the same at 1 atmosphere. However, at the last test stage, the current density and operating temperature were kept unchanged but the cathode pressure varied from 1 bar to 20 bar.

III. Results and Discussion

During the test, the test parameters were varied automatically through a script. The effect of current density was tested at the temperature of 60 °C, pressure of 1 atmosphere, and the current density between 1 A/cm^2 and 2 A/cm^2. Successively, the temperature was varied between 60 °C and 80 °C, at the test condition of 1 A/cm^2 and atmospheric pressure. The test period for each stage was 1 h for current density and temperature tests. Considering the safety issues for the pressure test, the test period was limited to only 15 minutes for each and the pressure was increased from 1 bar to 5 bar to 10 bar and to 20 bar gradually.

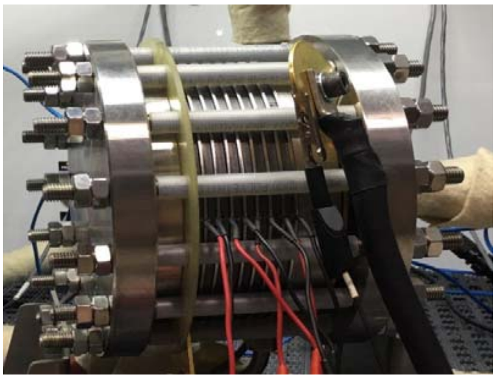


Fig. 1 The stack set-up

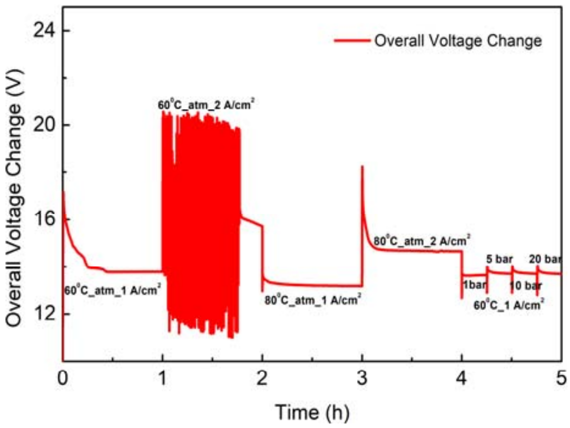


Fig. 2 The voltage change during the test period

The overall voltage of the 7-cell was recorded during the test. Besides, the polarization curve measurements were also carried out at each test stage to better present the stack performance change under each test condition.

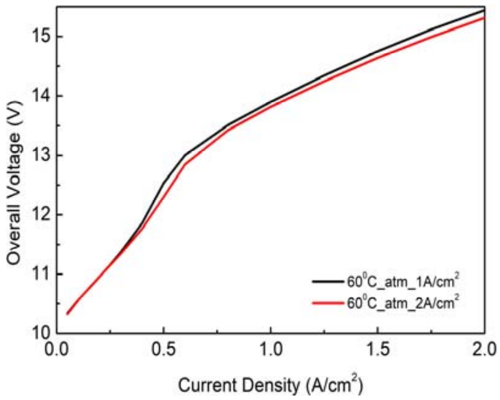
TABLE I
Test Protocols

	Current density	Temperature	Cathode pressure
Stage 1	1 A/cm^2	60 °C	1 atm
Stage 2	2 A/cm^2	60 °C	1 atm
Stage 3	1 A/cm^2	80 °C	1 atm
Stage 4	2 A/cm^2	80 °C	1 atm
Stage 5	1 A/cm^2	60 °C	1 bar 5 bar 10 bar 20 bar

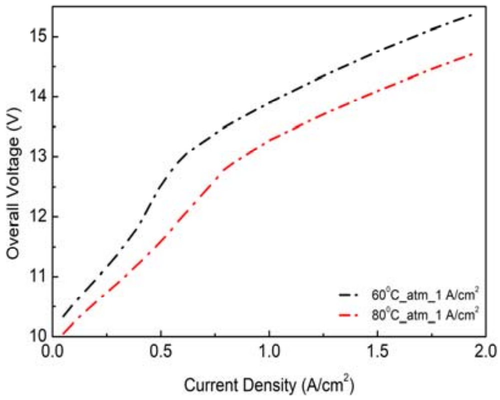
The results of the overall voltage of the 7-cell stack are shown in Fig. 2. As can be seen in Fig. 2, the stack performance experienced a break-in procedure at the beginning of the test, and the performance gradually stabilized at a stack voltage of 13.7 V at the condition of temperature of 60 °C, pressure of atmosphere and current density of 1 A/cm^2. At the second test stage, the operating temperature and pressure were kept the same as in the first stage while the operating current density increased from 1 A/cm^2 to 2 A/cm^2. As can be seen the performance of the stack at this test stage was not stable. This could be due to the fact that the current density increase from 1 A/cm^2 to 2 A/cm^2 improved the reaction kinetics of both hydrogen evolution and oxygen evolution on both sides [6], besides, the amount of the produced hydrogen and oxygen also increased on both sides, which led to unstable water and gas flow in the system and the corresponding unstable stack performance at this test stage. The stack voltage reached to 15.8 V at the end of the second stage, higher than at the current density of 1 A/cm^2.

For the third test stage, compared to the first test stage, the operating pressure and current density are kept the same, but the operating temperature increased from 60 °C to 80 °C. As can be seen in Fig. 2, the stack voltage reached to 13.1 V. Compared to the stack voltage obtained at 60 °C, when the temperature increased to 80 °C at 1 A/cm^2 and atmospheric pressure, the stack voltage decreased, lower than at 60 °C, representing an improved performance of the stack. This result illustrates that higher operation temperature of 80 °C contributes to better stack performance. This could be due to the increased reaction kinetics on both sides as a result of higher operating temperature [7]. However, at the fourth test stage, when increasing the current density from 1 A/cm^2 to 2 A/cm^2 at 80 °C, the voltage of the stack increased compared to the voltage of the third test stage, which was similar to the results of voltage increase obtained at test stage 2. This could be due to high current density of 2 A/cm^2 leads to the produced oxygen and hydrogen amount increased and thus results in large mass transfer resistance, which is responsible for the increased stack voltage at high current density. For the pressure test at the last test stage, though the cathode pressure was increased from 1 bar to 25 bar, the stack voltage did not experience great change.

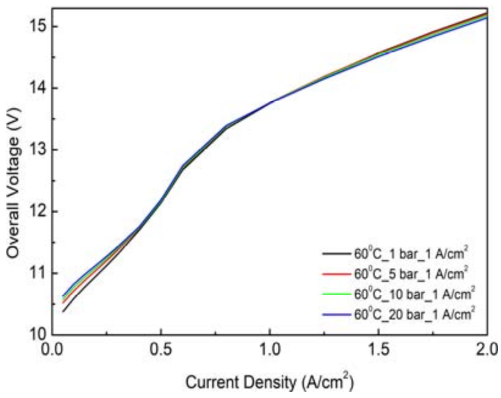
In order to fully analyze the effects of different parameters of current density, temperature and cathode pressure on the stack performance, polarization curves were recorded at the end of each test stage. The results are shown in Fig. 3.



(a)



(b)



(c)

Fig. 3 Polarization curves under different test parameters' effect (a) current density effect, (b) temperature effect and (c) pressure effect

Fig. 3 (a) shows the polarization curves obtained at different current density. As can be seen in Fig. 3 (a), the stack voltages at different current densities were the same at low current density (< 0.5 A/cm^2); however obvious difference appeared with current density increase. It is worth noting that higher current density contributed to lower stack voltage, which represents a better cell performance. This is reasonable because higher current density could increase the reaction kinetics on both of the electrodes and thus lead to lower charge transfer resistance [8], which contributes to better cell performance. Another explanation for the polarization curves in Fig. 3 (a) is that the differences appeared were probably a hysteresis effect caused by the current change [8], which means that the current density has little effect on stack performance.

The operating temperature effect on the stack performance is shown in Fig. 3 (b). It can be seen that there exists obvious voltage differences between the polarization curves obtained at 60 ^{0}C (black line) and 80 ^{0}C (black line). The stack voltage decreased greatly when the operation temperature increased from 60 ^{0}C to 80 ^{0}C. And the voltage differences between the two test conditions increased with the increase of current density. This could be due to that the higher temperature of 80 ^{0}C can help improve the electrocatalytic reaction rates of hydrogen evolution and oxygen evolution on both of the electrodes and reduce the charge transfer resistance on both sides, which will lead to better cell performance [7], [9]. Besides, the polarization curves at lower current density area are much steeper than the polarization curves at higher current area, which represent a bigger slop at the low current area. This could be due to that the reaction kinetics dominate the whole process of the stack at lower current density area, the charge transfer resistance is high with lower reaction kinetics and thus leading to bigger polarization slops. As mentioned above, higher current density can decrease the charge transfer resistance on both sides and the ohmic resistance dominate the high current density area, therefore, the slops of the polarization curves at high current density area is smaller.

The cathode pressure effect on the stack performance is shown in Fig. 3 (c), as can be seen that the polarization curves are almost coincident when the cathode pressure varied from 1 bar to 20 bar, the voltage difference was not so obvious during this test stage, which illustrate that the stack performance remained almost the same under different operating cathode pressures. Therefore, the cathode pressure effect on the stack performance is insignificant.

As reported by [1], the effect of current density on the performance of PEM water electrolyser is rather complex while the increase of operating temperature from 40 ºC to 80 ºC could strongly increase the membrane degradation. Besides, [10] found that the increase of operating temperature (from 60 ºC to 90 ºC) has a negative effect on the cell performance of PEM water electrolyser, where the degradation rate of cell was the smallest at operating temperature of 60 ºC while the highest degradation rate was achieved at the operating temperature of 90 ºC. Therefore, although the higher temperature can improve the cell performance to some extent, the membrane degradation is accelerated at higher temperature, which will lead to membrane thinning and the formation of hotspots and even cell failure.

IV. Conclusions

The effects of different operational parameters of current density, temperature and pressure on a 7-cell stack performance were investigated. Results showed that the temperature increase from 60 ^{0}C to 80 ^{0}C could improve the stack performance which could be due to that high operating temperature could lead to higher the reaction kinetics and thus contribute to better stack performance. The stack performance change was not very big when the operating current density increase from 1 A/cm^2 to 2 A/cm^2, which represents the effect of the operating current density on the stack performance is slight in this study. When the cathode pressure varied from 1 bar to 20 bar, the stack performance was kept almost the same during the test, illustrating that the effect of cathode pressure on stack performance is insignificant in a short test period.

It is obvious that the operating temperature effect contributed more than current density and cathode pressure to the stack performance in this study. Although increasing operating temperature could be a good way to achieve higher cell efficiency, higher operating temperature may also have negative effect on the membrane degradation which will lead to membrane thinning and even cell failure in the long-term operation. Therefore, the selection of operating temperature for PEM water electrolysis should balance the efficiency and durability of the cell.

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