Evaluation of the effect of reactant gases mass flow rates on power density in a polymer electrolyte membrane fuel cell

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Abstract. In this study it was experimentally investigated the effect of mass flow rates of reactant gases which is one of the most important operational parameters of polymer electrolyte membrane (PEM) fuel cell on power density. The channel type is serpentine and single PEM fuel cell has an active area of 25 cm². Design-Expert 8.0 (trial version) was used with four variables to investigate the effect of variables on the response using. Cell temperature, hydrogen mass flow rate, oxygen mass flow rate and humidification temperature were selected as independent variables. In addition, the power density was used as response to determine the combined effects of these variables. It was kept constant cell and humidification temperatures while changing mass flow rates of reactant gases. From the results an increase occurred in power density with increasing the hydrogen flow rates. But oxygen flow rate does not have a significant effect on power density within determined mass flow rates.

1. Introduction
In addition to the design parameters in PEM fuel cell, the operating parameters also have a significant effect on performance. The main objective of researches is to increase the performance by optimizing operating conditions of fuel cell. Thus, recently the basic operating principles of PEMFCs, especially for mass flow rates, humidity of the gases, membrane water transport mechanism were investigated by researchers, because it is an alternative power source for power generation and transportation.

In literature, several experimental works have been investigated in order to understand the effect of these operating parameters to the PEM fuel cell performance.

Salva et al. [1] in their work, they used 50 cm² PEM fuel cell using a one dimensional analytical model that provide the maximum power output for every value of current intensity to obtain different operating conditions of cell temperature, pressure, reactants relative humidity and cathode stoichiometry, in order to increase the performance of the PEM fuel cell. Their results showed that it is possible to use the analytical model to optimize the performance of the single PEM fuel cell.

Ozen et al. [2] investigated the effects of operation conditions like inlet gas humidification, inlet temperatures, operating temperatures and oxidant types on the performance of a PEM fuel cell which has a 25 cm² active area. Their results showed the cell exhibited higher performance when the pure oxygen was used. However, the improvement in the cell performance was higher when the cathode gas was humidified. Also after the optimizations, the cell showed 0.59 W/cm2 peak power at an operating temperature of 80 °C.

Yang et al. [3] conducted an experimental study to investigate the effects of various key operation parameters, for example cathode humidity, air stoichiometry, hydrogen pressure and operating current
density in a Dead Ended Anode fuel cell. It was presented that operating conditions have significant effects on water transfer in PEM fuel cells with a dead-ended anode.

Zhang et al. [4] in their paper investigated experimentally a steady-state performance and dynamic performance of a single High Temperature PEM fuel cell based on PBI membrane. One of the most important results of their study is that the performance of HT-PEM fuel cell reduced gradually after the purging and the shape of the dynamic voltage curve under the longest purging interval overlapped with that under shorter purging intervals.

Mu et al. [5] explored effects of the operation conditions such as the gas flow rate, relative humidity and temperature. The results showed that the maximum membrane water content difference decreases with the increasing gas flow rate because the gas flow rate benefits the dryness of the whole membrane. Also the maximum membrane water difference increased firstly and then decreased with the relative humidity.

Niroumand et al. [6] described a diagnostic technique, based on the above dynamics and was examined using a full-size (408 cell) PEM fuel cell stack, for characterization of the flow rates of Hydrogen. This method is also based on reducing the air flow rate from a high to low value at a fixed current, while maintaining an anode overpressure. It was shown that at low current densities and high air flow rates, hydrogen transfer leak has insignificant effect of the cell voltage. When the air flow was reduced, cell voltage exhibited an initial linear drop.

Zhang et al. [7] constructed a stacked microbial fuel cell (MFC) which has serpentine flow field to investigate the stack performance and response to cell number, connection type, variable loads and electrolyte flow rates. Their results showed that a large increase in the stack performance was observed after increasing the flow rate from 1 ml/min. to 10 ml/min., while no improvement was shown after a further increase in the flow rate.

For the objective of this paper, a single serpentine channel of PEM fuel cell which has 5x5 cm² active layer have been developed to investigate performance of fuel cell by determining the power density with different reactant gas mass flow rates at constant temperatures.

2. Experimental

Design-Expert 8.0 software trial version based on Response Surface Modelling (RSM) was used while determining optimum operating range of conditions. This program is used to create a mathematical model and the experimental results were evaluated to determine the optimum production conditions based on selected criteria. To obtain the graphics which provides the maximum and minimum power density for every value of mass flow rates, it was required to solve a parametric table with chosen combinations of the variables described in table 1. Also it is shown the schematic PEM Fuel Cell test system consisting of four parts, gas tank, mass flow rate controllers, temperature control panel and electric load in figure 1.

| Number of the tests | Chosen parameters |  |
|---------------------|------------------|---|
|                     | Cell Temperature (°C) | Humidity Temperature (°C) | H₂ mass flow rate (L/min.) | O₂ mass flow rate (L/min.) |
| 1                   | 60               | 55                           | 5                           | 4                           |
| 2                   | 60               | 55                           | 3.75                        | 4                           |
| 3                   | 60               | 55                           | 2.5                         | 4                           |
| 4                   | 60               | 55                           | 3.75                        | 3                           |
| 5                   | 60               | 55                           | 3.75                        | 5                           |

For each experiment, the parameters were set and then the voltage was adjusted in the range of 0.3–0.9 V. The current values that correspond to each voltage value in the test software interface were noted.
In experiments, 0.6 V corresponds to the value that refers to the current value. The values obtained as a result of experiments were entered into the Design-Expert software and graphics were created.

![Diagram of experimental test system of single serpentine PEM fuel cell](image)

**Figure 1.** Experimental test system of single serpentine PEM fuel cell.

In table 2, design parameters of experimental single serpentine PEM fuel cell which has 5x5 cm² active layers are given.

| Parameters                          | Value     |
|-------------------------------------|-----------|
| Channel depth (m)                   | 1x10⁻³    |
| Channel width (m)                   | 1x10⁻³    |
| Channel rib (m)                     | 0.370x10⁻³|
| Membran Electrode Assembly (m)      | 0.370x10⁻³|
| Active area (m²)                    | 25x10⁻⁶   |

**Table 2.** Design parameters of fuel cell

3. Results and discussions

Examining the effect of the oxygen flow rate to the power density, the anode inlet mass flow rate (H₂), 3.75 L/min, humidification temperature and the cell temperature were respectively taken as 55°C and 60°C as constant value. According to figure 2, it can be seen that increasing of the oxygen flow rate does not cause a significant change in the performance of the fuel cell. But reaction rate increases with increasing oxygen flow rate. Increasing the flow rate slightly improved the performance.
Figure 2. Effect of variable O$_2$ mass flow rate on power density at constant temperatures.

In figure 3, the effects of H$_2$ mass flow rates on power density at 55°C humidification temperatures and 60°C cell temperatures are shown. It can be seen from Figure that the performance increased with increasing hydrogen flow rate. One of the reasons for this increase is that the high hydrogen flow rate also helps for the removal of liquid water in the channel. However, the gas diffusing layer is prevented from flooding. When it is been considered in both figure 2 and figure 3, the cell temperature was taken as 60°C. Because the highest power density was obtained at this average temperature value for all mass flow rate values examined.

Figure 3. Effect of variable H$_2$ mass flow rate on power density at constant temperatures.

In figure 4, it is shown that variation of different mass flow rates of reactant gases on power density as results of experimental study. While O$_2$ mass flow rate does not affect too much the performance of the cell, the increase in H$_2$ mass flow rate is increased the power density up to a certain level.
Figure 4. Variation of different mass flow rates of reactant gases on power density.

4. Conclusions
In this work, the effects of O\textsubscript{2} and H\textsubscript{2} mass flow rates on the power density of PEM fuel cell, which has 25 cm\textsuperscript{2} active areas, have been examined experimentally. Other operation conditions as cell and humidity temperature kept constant. It has been seen that there is no point in increasing the oxygen mass flow rate too much. The results of power density show that operating with the conditions of 5 L/min. H\textsubscript{2} and 4 L/min. O\textsubscript{2} it reaches a maximum value of 230mW/cm\textsuperscript{2}.

5. References
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