Analysis of Operating Temperature, Humidification Temperature and Oxidant Composition based PEM Fuel Cell Performance.

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***Abstract*:**

Polymer electrolyte membrane fuel cell (PEMFC) achieved great attention in the recent years because of efficient energy production with zero toxic emission. The overall performance of PEM energy cells is determined by many parameters such as fuel/oxidant ratio, operating and humidification temperatures. In this paper, Sequence of polarization curves have been analyzed with different fuel cell operating temperature, humidification temperatures, and mass (oxygen) transfer ratio and can be calculated to measure the performance factors of Fuel cell.

***Index Terms*:**

Fuel cell/energy cell, Operating temperature, Humidification temperature, activation loss, Ohmic loss, mass transport loss.

I. INTRODUCTION

Power is regarded to be way of lifestyle wide range of any economic system and most essential system of socioeconomic growth of a country. The gap between demand and supply has been constantly increasing. Serious power issues have seriously affected the professional and cost-effective actions in the country. Fuel cells, as an effective transformation technology, and hydrogen, as a clean power service provider, have great potential to give rise to dealing with power challenges. Fuel cell is basically an electrochemical system which makes electrical energy silently without going to combustion process. Figure 1 is a diagram of a fuel cell. Fuel cell is basically made of electrolyte sandwiched between two electrodes cathode and anode associated channels to deliver H2 & O2 and channels for the removal of byproducts (i-e) water and heat.[1]

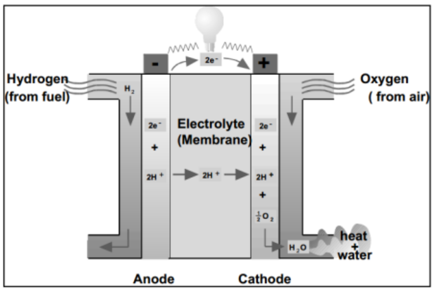

Figure 1: PEM Fuel Cell.

The basic principle of PEM is introduced. Fuel (hydrogen) is supplied to the fuel Cell where hydrogen atoms are split into positive ions (protons) and negative ions (electrons). The chemical reaction at anode is:

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

The proton passes through an electrolyte membrane that does not allow the electron to the cathode layer (catalytic coated) . There for the electrons are bound to follow the path by means of the external circuit producing an electric current. On the other end of the cell, the oxygen, electrons and protons are combined forming water and heat in the surface of catalytic particles. The chemical reaction at cathode is

$$4H+ \quad 4e^- + \quad O_2 \rightarrow 2H_2O$$

Finally, the overall process in the fuel cell can be summarized as.[2]

$$2H_2 + O2 \rightarrow 2H_2O + \quad \text{heat + electricity}$$

II. WORKING

At high temperature fuel cell response in an effective output and improves the functionality in relation of catalyst tolerance, response kinetics, water and heat being rejected management. High comparative moisture is essential in order to acquire a realistic performance if the membrane is not properly hydrated it will show high ionic resistance which damage the membrane in extreme situations. In order to maintain high proton conductivity polymer membrane used in the cell must be hydrated and at the same time the water produced as a byproduct must be removed to prevent flooding.[3]

III. CURRENT-DENSITY AND VOLTAGE CURVE

The most essential attribute of a fuel cell is its polarization/ current-voltage curve which show the overall effectiveness of the energy cell. This curve shows the change in the performance of fuel cell with changing humidification, catalyst loading, operating conditions and uniformity of local condition over the entire active area.[4] The electrochemical reaction that occurs in the fuel cell can be shown as under:

Anode Reaction: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode Reaction: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Maximum potential per mole of hydrogen for a fuel cell is 1.22Volts determined by adjustment in Gibbs free energy. In the polarization cure, the maximum potential of the fuel cell can be shown as the green horizontal line. This line shows the ideal or theoretical potential in which there are no losses.

The current density Vs voltage curve depends on the losses that occur in fuel cell when load is connected to it which are activation losses, ohmic losses and mass transport losses.

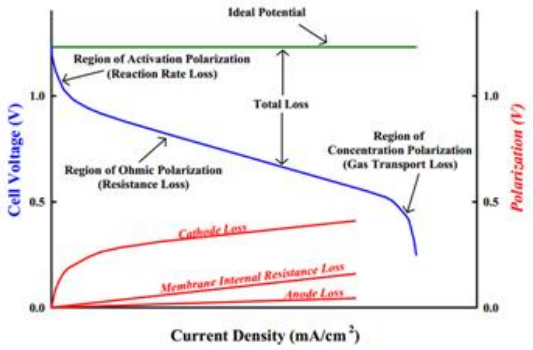

Figure 2: Fuel cell performance curve.

1) *Activation losses:*

Activation losses or activation polarization is because of the slow reactions for activation of the fuel cell at both sides (cathode and anode). The activation energy barriers are related to temperature, pressure, and concentration and electrode properties.[5]

The activation polarization deviates less from the ideal curve and in this region there are much of the reactants are available for mass transfer and ohmic losses are very less.[6]

2) *Ohmic losses:*

PEM ohmic failures are usually due to both, the level of resistance that provides the tissue layer to the protons exchange and the electric level of resistance of electrodes and collectors. These failures can be decrease by helping the ionic conductivity of the electrolyte.[5]

3) *Mass transport losses:*

Another type of failures known as mass transport failures that happen when the reactants are quickly absorbed at the electrodes by the electrochemical responses, then concentration gradients are established.[6] This region is also called concentration region in the polarization curve.

From the polarization curve, it can be seen that the losses at cathode (concentration region) are greater than both anode(activation losses) and membrane internal losses(ohmic losses).

IV. CIRCUIT DESCRIPTION

Figure 3 shows an test installation of PEM fuel cell stack. The test arrangement includes 300 W fuel cell stack with 20 cells individually. Under maximum circumstances regarding to moisture, stress, heat range and reactants circulation, 300 w is the electric outcome ability of the stack. Air which is to be supplied from cathode side is managed by a air compressor the hydrogen is stored up to 200 bar in a high pressure tank. The fuel cell stack are fed with hydrogen and air using reduction valves, an external humidifier and mass flow controllers. To assist the elimination of water minute droplets in the flow channels purge valves were used. The whole system is equipped with the liquid cooling loop comprises of a heat exchanger and continuous control pump. Thermocouples are used to measure the temperature under Galvonostatic conditions. All tests were performed using a 500 W H and H electronic load.

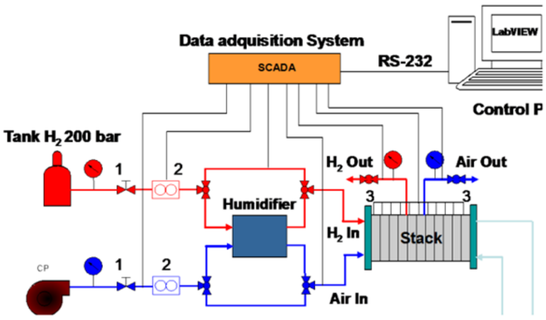

Figure 3. test installation of fuel cell stack consist of hydrogen supply, air supply, humidifier system, cooling system and data acquisition.(1) reduction valves, (2) mass flow controllers, (3) elimination valves.

In this research the performance of fuel cell stack was calculated at different humidification temperature from 40 to 70 C and operation temperature from 20 to 80C. Hydrogen is supplied with fixed rate at which being consumed. In this experiment the measurement of hydrogen flow rate was not controlled but can only be measured, while air is provided with a stoichiometric ratio of 5, having 1 bar operation pressure.[3]

V. RESULTS AND DISCUSSION

A. Effect of oxidant composition and membrane resistance on the polarization curve for an operational temperature 80 ^{o}C

Polarization curve that is obtain from different oxidant arrangements (pure oxygen, air, 10.5% O2 in N2 , and 5.25% O2 in N2) for an operational temperature 80 ^{o}C are shown in figure 4. Activation polarization is observed at low current density (0-150mA/cm2) , with the loss in oxygen concentration kinetic losses increases. Membrane resistance (ohmic polarization) is independent of oxidant composition and is nearly constant at low current densities. due to dry out of the membrane on anode side membrane resistance increases with increasing current densities at $800mA/cm^2$. at high current density dry out occurs because of the positive ions of water molecule are taken from anode part to cathode at better pay than they can dissipate back . Gasses having low concentrations of oxygen show mass transport restriction due to inadequate supply to the outer lining area at high current density. For oxygen(pure oxygen) restricting current solidity is not apparent in this plot.[4]

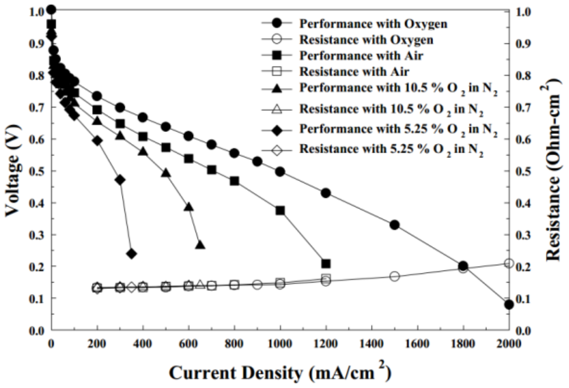

Figure 4: Effect of oxidant focus on the performance of PEM fuel cell and membrane resistance

B. Effect of operating temperature on membrane resistance and cell performance for a pure O2/H2.

Performance of cell at different operation temperature for pure O_2/H_2 is show in figure 5. Because of fast kinetics on the surface catalyst and lower membrane resistance the performance of cell (PEM) increases due to increase in function temperature. When humidification of membrane is increases membrane resistance reduces with improve in function heat range which results in the increase mobility of proton. For pure oxygen limiting current density is not obvious in this plot. [3]

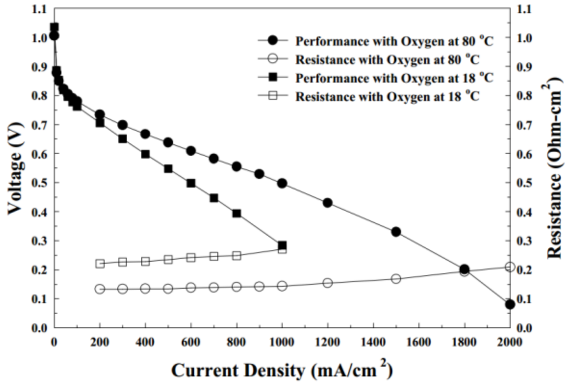

Figure 5: Effect of function temprature on the efficiency of PEM energy cell and membrane resistance.

C. Energy cell (PEM) performance based on operating heat range in the lack of humidification heat range.

The performance of the fuel cell stack was determined at operating temperature of 20ºC to 60ºC. It was noticed that the performance of energy cell was improved with increase in temperature because of improved gas diffusivity and membrane conductivity at high temperature. Therefore the reaction is favored at high temperature.[3]

However if the temperature is further increased, the membrane dries out.[3] because at high temperature the water produced will be evaporated and the membrane conductivity will be decreased shown in figure 6.

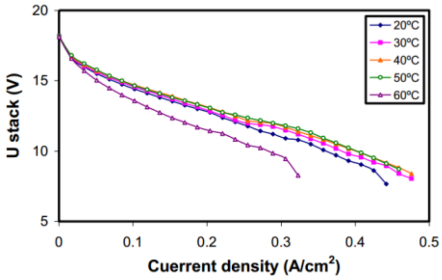

Figure 6: Energy cells (PEMFC stack) performance based on working heat range in the lack of humidification temperature.

D. Energy cell stack (PEMFC) performance based on humidification temperature.

To assess the performance of energy cell, the effect of the operation and humidification temperature has been studied simultaneously. By varying the function heat range of fuel cell stack from 20ºC to 80ºC and the fuel humidification heat range from 40ºC to 70ºC, it was noticed that both the function and humidification heat range impacts the performance of fuel cell stack. It is shown in the figure 7 below.[3]

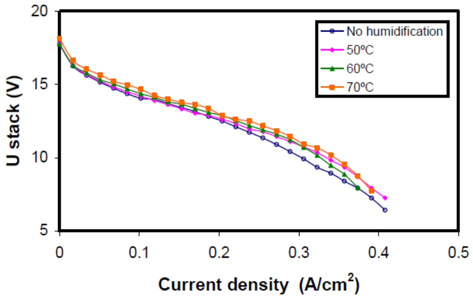

Figure 7: Humidification temprature based fuel cell performance.

The performance of the fuel cell enhances with the increase in humidification temperature by keeping the operation temperature at 60ºC as shown below in figure 8.[3]

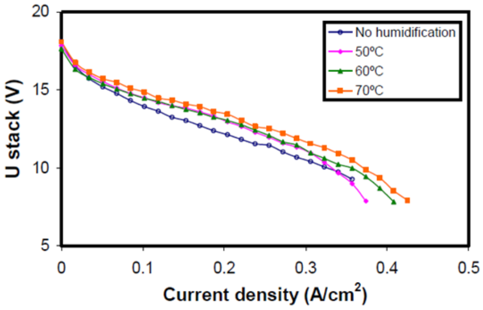

Figure 8: performance of fuel cell stack

At low humidification temperature (40ºC), by changing the operation temperature from 50ºC to 70ºC fuel cell stack performance decreased because of the dry out of membrane at low humidification temperature. It can be shown in the figure 9 below.[3]

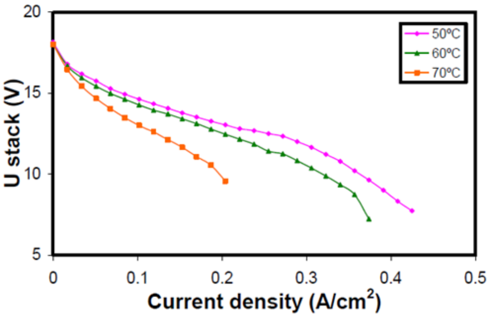

Figure 9: Impact of the function heat range on the polarization shapes for a humidification heat range of 40 ºC.

At high humidification temperature of 70ºC the fuel cell stack performance increased with increase in the operation temperature as shown in the figure 10.

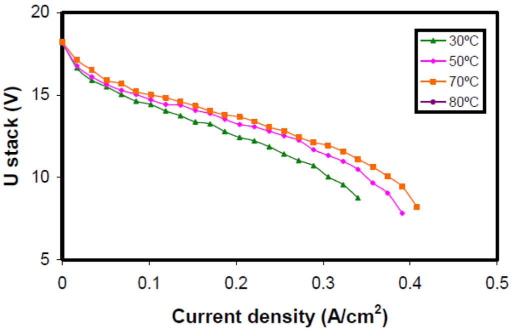

Figure 10: Impact of the function heat range on the polarization shapes for a humidification heat range of 70 ºC.

It can be concluded that by increasing the humidification temperature along with operation temperature results in better membrane conductivity and gas diffusivity. Hence activation losses are reduced.[3].

VI. CONCLUSION

In this paper the effect of oxidant concentration, operation temperature and humidification temperature of 300 W PEM fuel cell stack is evaluated. The curve shows that the fuel cell performance will increase if the operation temperature and humidification temperature increases correspondingly. As the humidification temperature increases, membrane material humidifies in the catalysts layer, and improves the active area of the switch levels which leads to enhancement of energy cell. But if operation temperature is increased in the absence of humidification the water get evaporated and the membrane start to dry, which decreases the membrane conductivity. Therefore to gain maximum efficiency higher operational temperature and humidification temperature is required.

Polarization curve obtain by varying the oxidant composition, operation and humidification temperature, which shows that performance of fuel cell will increases if the oxygen composition contains maximum ratio of oxygen with the suitable increase in operation temperature.

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