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Fax: 977-1-5525830

# EXPERIMENTAL STUDY ON PERFORMANCE CHARACTERISTICS OF A PEM FUELCELL

**Er. B. B. Ale, Ph.D.**
Prof. Mechanical Engineering Department, Pulchowk Campus, Institute of Engineering, Tribhuvan University

**Er. S. O. Bade Shrestha, Ph.D.**
Associate Prof. Department of Mechanical and Aeronautical Engineering, Western Michigan University
Kalamazoo, MI, USA

**Abstract:** The performance of a PEM fuel cell was investigated for different operating conditions. The fuel cell was tested for different dew point temperature of humidifier, the stack coolant temperature, and stoichiometric of fuel and air supply conditions. The higher stack coolant temperature, humidity, as well as stoichiometric of reactants produced enhanced performance of the fuel cell as expected. The effect on the cell voltage and efficiency were more pronounced as the current density was increased to medium and high levels. The deteriorating and degradation effect of the performance of the fuel cell was also observed during the test span.

## 1. INTRODUCTION

Recently, International Panel of Climate Change (IPCC) has indicated that the Global Warming is one of the most challenging problems that the man kind is facing in the 21st century and it is attributed to the manmade green house gases released indiscriminately to the atmosphere [1]. The major part of this emission comes from burning of fossil fuels for energy production and motive power. This problem is even more aggravated due to development of the developing counties including big countries like China and India, that created a huge demand in fossil fuels in order to meet increasing living standards of their citizens. The demand considerably put a high pressure in the already depleted world fossil reserves and pushed the price of the petroleum oil incredibly high in international market in the recent years. This has strongly renewed the concern of the energy securities and political and economical stability.

Hence, the utilization of alternative sustainable and renewable energy sources is imperative to overcome the global warming problem and the energy security concern. It is particularly even more important for the countries, which do not have a petroleum reserve but have enormous quantities of renewable energy sources such as hydro power in Nepal. This will provide not only the energy independence, but also make energy - a carbon free eliminating the whole global warming problem. The plausible solution for the energy need of future is to use hydrogen as a fuel that can be generated from the renewable energy sources and be use to power vehicles, homes and industries, making carbon free energy environment of future. Therefore the degree of carbon free energy would be defined by the way how hydrogen is generated.

A fuel cell is the electrochemical energy conversion device where continuous electricity is generated through the external supply of hydrogen and air in presence of electrolyte and producing just water as a product in the process. Thus, the fuel cell technology presents a huge economical and environmental potential for next generation

of power systems because it can provide in comparison with the conventional internal combustion engines both more efficiency and reduction in emission [2,3,4]. Among different types of fuel cells, the proton exchange membrane (PEM) fuel cell due to its low operating temperature, high efficiency, simplicity with no moving parts, silence operations, and ultra low emission, is considered to be the future power source as a replacement for the conventional internal combustion engines in automotive and other applications.

However, the high cost and short durability of the PEM fuel cell are being the main barriers at present towards commercialization of the PEM fuel cell. To meet the challenges, tremendous research efforts have been made in the areas of experimentation, analytical analysis and modeling and simulations in the recent years. The contribution of the present work is to investigate experimentally the effects of various operating parameters such as dew point temperature, stack coolant temperature, gas flow rates and gas temperatures on the performance of a PEM fuel cell.

## 2. EXPERIMENT SET-UP DESCRIPTION

The experimental investigation was carried out using a 50 watt PEM fuel cell stack with 5 cells of a 100 $cm^2$ surface area (Figure 1). The fuel cell was manufactured using DuPont MEA5 membrane. This test fuel cell was connected to a test bench of Arbin Instruments Fuel Cell Test Station (Figure 2) that was run by a MITS Pro-FCTS software and autonomously carried out the predetermined test and recorded data in the data acquisition computer system.

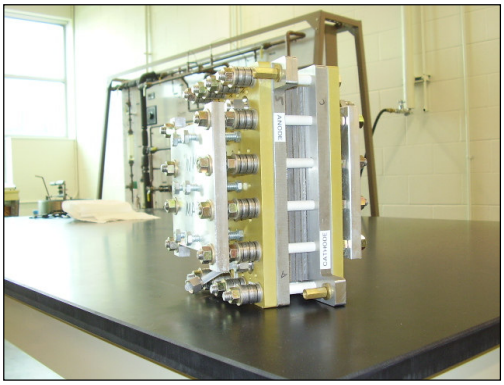


Figure 1: The Test PEM Fuel Cell

Arbin's FCTS was consisting of five basic subsystems: gas handling module, cooling water module, humidifier module, power module and control module. The gas handling module composed of fans, sensors, relays and alarms and mechanical tubing, mass flow controls (MFC), rotameters, regulators, gauges, filters, drains and valves. Two level of MFC were installed into both fuel and oxidant lines in order to test wide range of fuel cells ranging from very small to 3 KW power output capacities. In order to maintain the required temperature of the test fuel, the cooling water handling system was composed of water rotameters, heat exchanger, thermocouples, heaters and flow controls. The humidifier module provided the required humidity in both fuel and oxidant channels employing Arbin's proprietary dew point humidification system. The power module was composed of the transformer, diodes, contactor, relays, terminal block and fuse holders related to input power and output AC to heaters, pumps and axillaries. The control module was composed of the auxiliary inputs and outputs associated with the monitoring of environmental and experimental conditions, discharge circuitry, emergency and main power switches, and heat coil control and was connected with the computer through the Ethernet card.

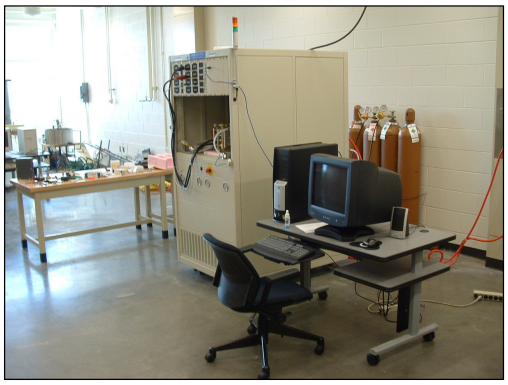


Figure 2: The Fuel Cell Test Station

During the experiment, the fuel hydrogen was supplied through the cylinder bottles with 99.998% purity and the inlet pressure was maintained at 60 psi (414 kPa). Nitrogen also was supplied using the cylinder bottles for purging as shown in the schematic diagram in Figure 3. Air was supplied from the compressed air supply line through a regulator and a filter as an oxidant in these tests. Both fuel and air were humidified using de-ionized (DI) water before entering into the test fuel cell. The excess fuel and air were exhausted to the atmosphere after condensing the water in the both channels at the back pressure of 10 psi (69 kPa). Chilling and DI water was connected to the continuous supply taps in the lab.

## 3. TESTING PROCEDURES

Before starting an experiment leaks were checked and repaired if there was any. The taps of cooling water, de-ionized water were opened and then a switch was turned on to start the test bench. Electrodes of PEM fuel cell were connected to E-load of the test bench. Using the interface software, dew point temperature (DPT), gas temperature (GT), stack coolant temperature, reactants flow rate, stack coolant flow rate were selected. Since the dry membranes and flooded fuel cells cause high polarization losses it was very important to maintain the correct humidity of flowing reactants. For example, the humidity of air should be about 80% to prevent excess drying, but must be below 100%, or liquid would collect in the electrodes [3]. Gas temperature was kept higher than dew point temperature by ΔT more than 10ºC. GT equal or lower than DPT could cause condensation of water vapor in the gas line and could interrupt the operation. For initial setting the DPT and GT were chosen greater than 40ºC and 50ºC respectively. Then the system was warmed up with the supply of fuel and air at the specified flow rate to the fuel cell until the set temperatures were reached. It took 3-4 hours to reach the set temperatures. Then the tests were conducted using the test schedule using the MITS_Pro software. The tests were repeated at least three times for the consistence and reproductively of the data.

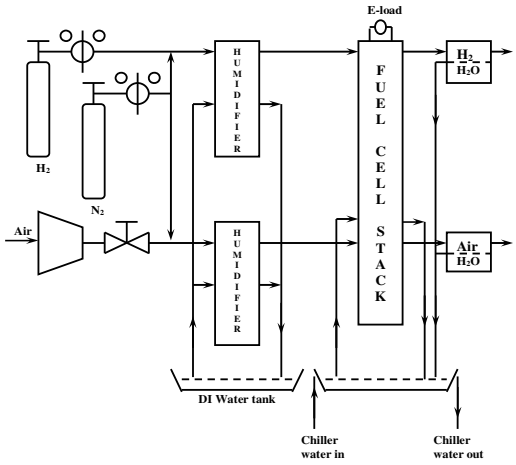



Fig 3. Schematic diagram of the PEM fuel cell testing system

## 4. RESULTS AND DISCUSSIONS

A typical fuel cell polarization of current and voltage curve was presented in Figure 4. It illustrates the change of the cell voltage with respect to the current load in a fuel cell. As it can be seen in Figure 4, the cell voltage of a fuel cell in operation is always less than the voltage given by the Nernst potential, due to the existence of various kinds of potential

losses. The dotted horizontal line in the figure corresponds to the maximum theoretical voltage given by the Nernst equation and the solid line represents an output voltage of a cell. As can be observed in the figure, there are three major losses in operation of a fuel cell: activation losses, resistance losses and mass transport losses. During the low current density operation, the major losses occurs due to the activation or the kinetic losses which can be evaluated using the Tafel equation [2,3,4,5]. These are caused by the slowness of the reactions taking place on the surface of the electrodes and a proportion of the voltage generated is lost in driving the chemical reaction that transfers the electrons to or from the electrode. This voltage drop is highly non-linear.

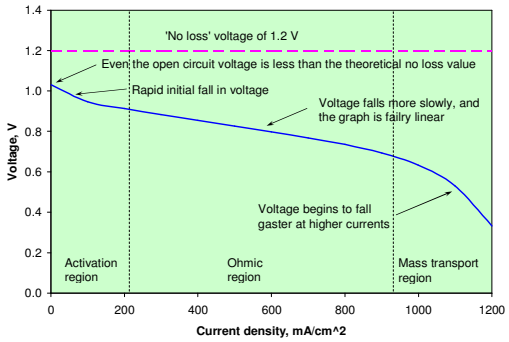



Figure 4: Voltage-current density curve, showing voltage drop due to the different losses [3]

At the medium current density operation of a fuel cell, additional resistance losses are the major factor that affects the cell voltage. This voltage drop is the straightforward resistance to the flow of electrons through the material of the electrodes and the various interconnections, as well as the resistance to the flow of ions through the electrolyte. It is essentially proportional to current density, and so is called *Ohmic losses* or sometimes as resistive losses. The magnitude of the ohmic losses is usually material dependent. During the high current density operation, as can be seen in the figure, the change in concentration of the reactants at the surface of the electrodes, as the fuel or oxidant is used, is controlling the electrochemical process. Because, the reduction in concentration is the result of a failure to transport sufficient reactant to the electrode surface, this type of loss is often called mass transport losses.

In addition, due to fuel crossover and, to a lesser extent, the internal current across the membrane, an open circuit voltage losses may occur. This energy loss results from the waste of fuel passing through the electrolyte, and, to a lesser extent, from electron conduction through the electrolyte.

Therefore, the actual efficiency of a fuel cell is far away from the ideal fuel cell efficiency which can be defined as the ratio of changes in the Gibbs free energy to the total thermal energy available. The actual cell potential is dropped from the ideal potential due to various irreversible losses described above and shown in Figure 4.

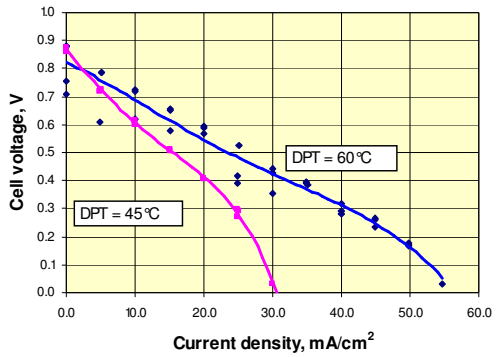
Furthermore, the efficiency, power and cell voltage are strongly depended upon the operating parameters such as humidity and water content, gas temperature and pressure, stoichiometric ratio and stack coolant temperature, especially, it is critical for the fuel cells operating in low temperature such as PEM. For example, ion conductivity of the membrane electrode assembly (MEA) of a PEM fuel cell, generally made of Nafion, may be varied in magnitude of order relative to the small changes in humidity [6,7].

## Effect of DPT on voltage, power and efficiency

Typical results of the experimental investigation of effects of humidity on cell voltage, power and efficiency of the test fuel cell were presented in Figure 5. As can be seen in the figure, the results were shown for two dew point temperature cases of 60ºC and 45ºC at the constant reactants flow rate, gas

temperature and stack coolant temperature. The flow rates of air and hydrogen are kept at 5slpm (standard liter per minute) and 1slpm respectively. Similarly the gas temperature and stack coolant temperature were maintained at 75ºC and 70ºC respectively. The relative humidity corresponding to DPT 45ºC and 60ºC with respect to gas temperature of 75ºC were 27% and 54% respectively.

Though both cases had relatively low levels of humidity, the cell voltage dropped significantly at low DPT (45ºC) causing lower power output and lower efficiency compared to high DPT (60ºC) in Figure 5. Figure 5(b) shows substantial decrease in power after electrical load of 1.5A and the cell voltage reached zero at 3A for the DPT equal to 45ºC, whereas the maximum power of about 7W at electrical load of 3A was observed at DPT 60ºC. Though current density values for the test fuel cell were comparatively low due to the degradation of the test fuel cell caused by a long period of storage, the trends observed were in consistence with the data reported in literature [6,7,8,9,10,11]. It can be also noted that the influence of the humidity at low current densities was significantly lower than at the high current densities. Therefore, the membrane resistance was largely dependent on the humidity, and particularly, at high current output, it was necessary to make sure that the membrane was wetted in these conditions [8]. However, at large current density, the water produced at the cathode and mitigated from anode caused cathode flooding effect, thus, decreasing the cell performance.

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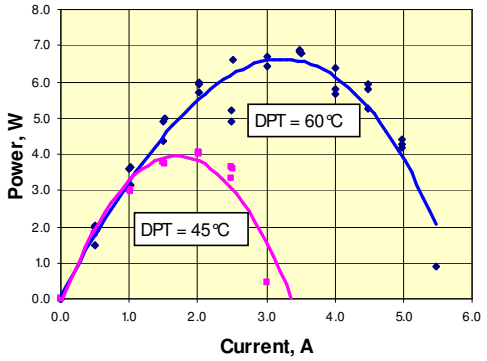


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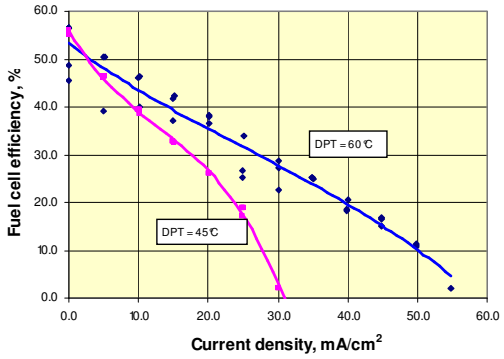



c)

Fig 5 The effect of dew point temperature on the cell voltage, power and fuel cell efficiency at flow rates of air 5slpm, hydrogen 1slpm, gas temperature 75ºC and stack coolant temperature 70ºC.

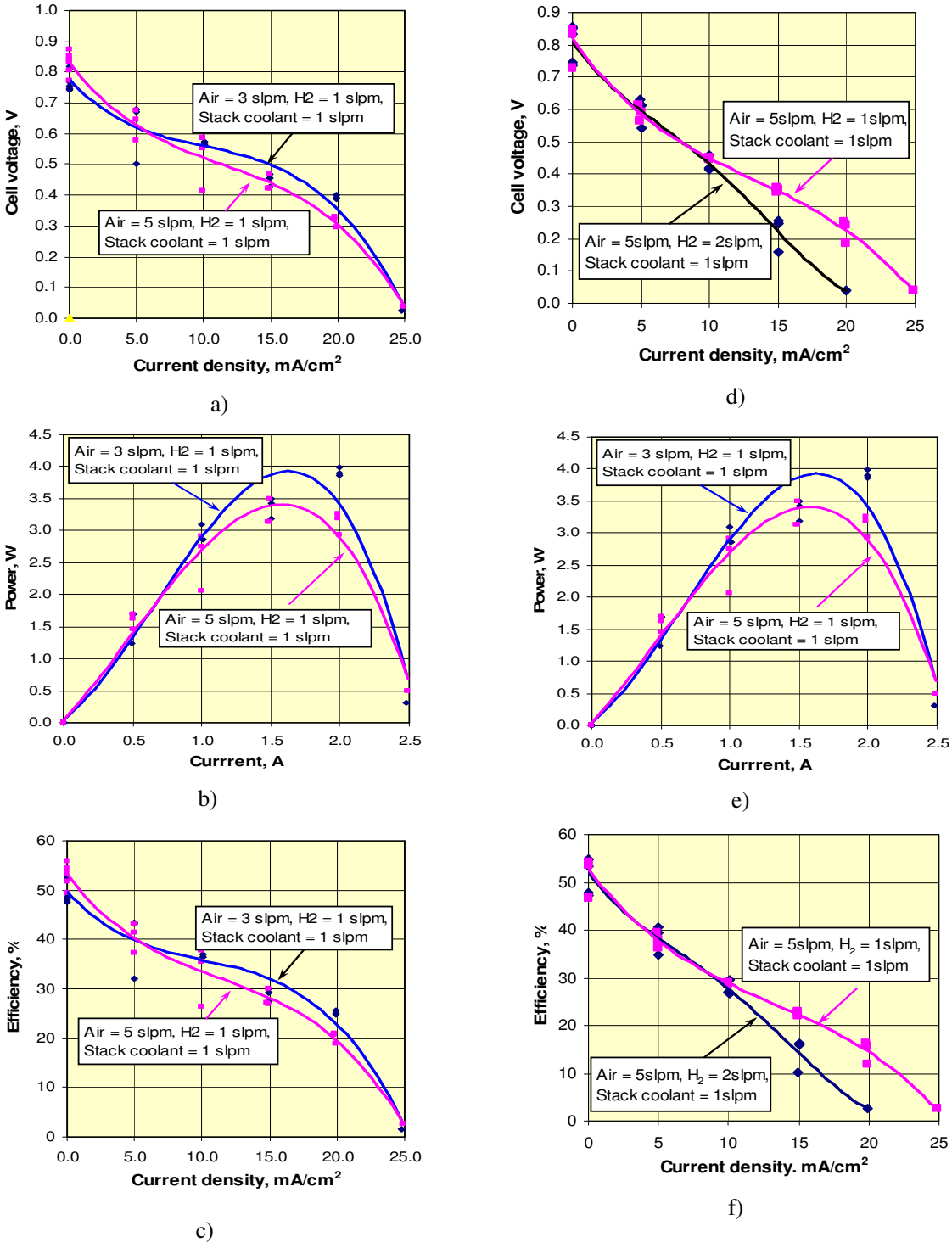



Fig 6: The effect of reactant flow rate on the cell voltage, power and fuel cell efficiency at DPT 65ºC, gas temperature 75ºC and stack coolant temperature 70ºC (a,b,c) and DPT 55ºC, gas temperature 65ºC and stack coolant temperature 60ºC (d,e,f) respectively

Fuel cell efficiency is directly proportional to the fuel cell voltage. As can be seen in Figure 5 (c), increasing the current density lowered the fuel cell voltage, thus decreasing the fuel cell efficiency. Therefore designing a fuel cell with higher efficiency increases the cost of materials but decreases the fuel cost and heat dissipation requirement for the same power output.

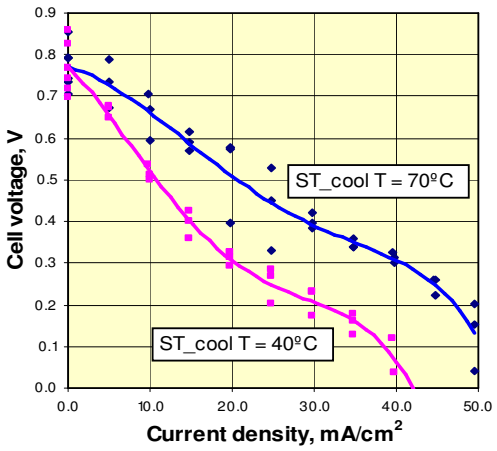
**Effect of air and fuel flow rate on voltage, power and efficiency**

The fuel and air stoichiometries were one of the very important parameters in operating a fuel cell. During the experiment, two flow rates of air and hydrogen were investigated and other parameters such as stack coolant and gas temperatures, DPT were kept constant. Figure 6 represented the test results of different reactants flow rate at constant gas temperature, stack coolant temperature and dew point temperature. In Figure 6 (a,b, c) the flow rates of air were fixed at 5slpm and 3slpm with the constant hydrogen flow rate of 1 slpm. The gas temperature, stack coolant temperature and dew point temperature were maintained at 75ºC, 70ºC and 65ºC respectively. The hydrogen flow rates were fixed at 2 slpm and 1 slpm with the constant air flow rate of 5 slpm in Figure 6 (d, e, f). The DPT of 55º C, gas temperature of 65ºC and stack coolant temperature of 60ºC were used in this case.

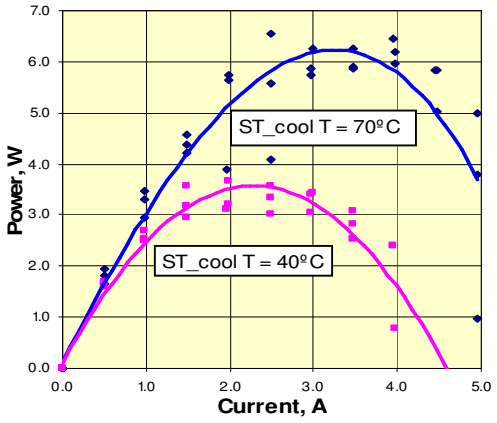
As can be seen Figure 6 (a, b, and c) that with the increase of the flow rate of air from 3 slpm to 5 slpm, thus increasing the access air number "lamda", had marginally improved the performance of the cell at very low current density values, however the performance were reduced noticeably at the higher current density which was an indication of drying effects of the high flow rate of air [11]. The reduction of the maximum power output was about 10 %. Similarly, drying effects of the hydrogen flow rate increased were visible in Figure 6 (d, e and f) particularly at higher current density operations [11]. The max power output was reduced by about 25 % for the case as all these test conditions were very lean.

**Effect of stack coolant temperature on voltage, power and efficiency**

The stack coolant temperature can change the performance of fuel cell significantly [11, 12, 13]. Figure 7 showed the test results of different stack coolant temperatures at constant reactants flow rate, gas temperature, and dew point temperature. The constant flow rates of air and hydrogen at 3slpm and 1.25slpm respectively were tested at stack coolant temperature of 40ºC and 70ºC respectively.




a)

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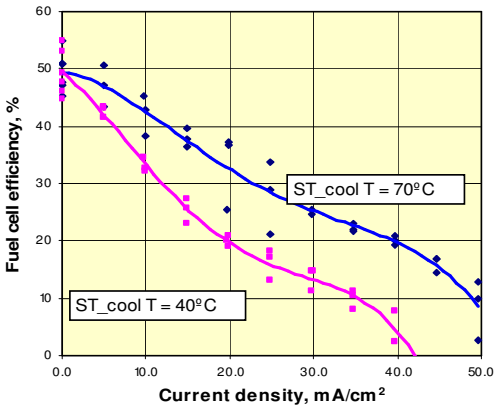


c)

Fig 7 The effect of stack coolant temperature on the cell voltage, power and fuel cell efficiency at DPT 60ºC, gas temperature 75ºC and flow rates of air and hydrogen equal to 3slpm and 1.25slpm respectively.

The gas temperature and dew point temperature were maintained at 60ºC and 75ºC respectively. As can be seen in Figure 7 the cell voltage decreased monotonically with the increased in the current density owing increased in resistance losses in membrane and activation and concentration losses in the catalyst regions as expected [12]. For a given current density, the performance of the fuel cell at stack coolant temperature at 70ºC was much better than the performance at 40ºC (Fig 7). For example, the current density was 20mA/cm$^2$ and 40mA/cm$^2$ at 40ºC and 70ºC respectively for the cell voltage of 0.3V (Fig 7a). Similarly, the maximum power output was about 3 W with current of 2 A for the stack coolant temperature of 40ºC in comparison of about 6.3 W with current output of 3 A for the stack coolant temperature of 70ºC (Figure 7 b). The efficiency was almost double in value at the current density of 25mA/cm$^2$, for the high temperature case. The trends of the performance of the fuel cell were in agreement with the reported literature [11, 12, 13] that the high cell temperature enhanced the performance due to reduction in losses, thus improving ion conductivity of the membrane.

### Test time vs power at constant current

One of the challenges of the fuel cell designer has been the longer durability [14]. The test fuel cell had been tested at constant current load of 5A and 2A for 10 minutes in different period of time with the flow rate of air, hydrogen and stack coolant at 5slpm, 1slpm and 1slpm respectively. It had been noticed that the power generated by the fuel cell was deteriorating with the span of its uses. The performance of fuel cell found deteriorated by 78 percent during the test time as shown in Figure 8. The results might be attributed to degradation and deterioration of catalyst regions during the course of the test. The problem was more exaggerated due to the long storage of the test fuel prior to using for this investigation.

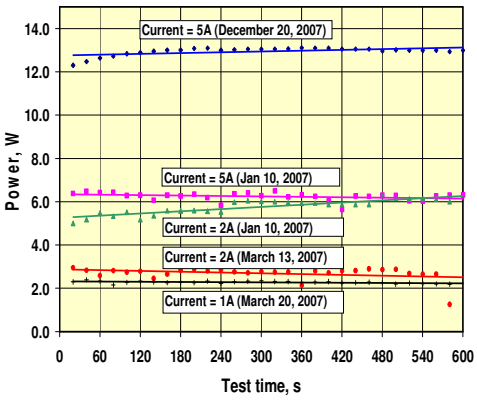


Fig 8: Recorded power generation of fuel cell at different constant current load at different time

## 5. CONCLUSIONS

The performance of a PEM fuel cell was experimentally investigated and found that the various operating parameters affected considerably in the efficiency and power output of the fuel cell. The operating conditions considered were the dew point temperature of humidifier, stoichiometric of reactants and stack coolant temperature. The power output was increased by about 70% whenever the humidity was change from 27% to 54%. The cell voltage and efficiency

were affected increasingly more as the current density were increased. The increase in stoichiometric number or access fuel or air coefficient found had noticeable affects in the performance of the fuel cell particularly during the higher current density operations. Operating of the fuel cell at $70^{o}$ C stack temperature was found to increase the power output by about 80 % than operating at $40^{o}$ C. The effects of the temperature on the cell voltage and efficiency were augmented as the current densities were kept higher. The deterioration and degradation of the test fuel cell was noticeable during the test period.

## 6. ACKNOWLEDGMENTS

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