INVESTIGATIONS ON POWER DENSITY FROM PROTON EXCHANGE MEMBRANE FUEL CELL FOR POWER GENERATION FROM SOLAR ENERGY

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Abstract

A study has been carried-out on proton exchange membrane fuel cell (PEMFC) by using a new chemical coupling 2-propanol/acetone/hydrogen that will support solar power generation. The paper presents results of the study made on the power density from PEMFC based on the new chemical coupling proposed to be used in solar power generation. Some investigations have been performed on electro-catalyst in the PEMFC and power density $2.06 mW/cm^2$

has been achieved with hydrogen flow rate at 15ml/M and liquid oxidant flow rate at 0.74ml/M. The PEMFC will have its future scope in the solar energy field for power generation as it is considered to be highly efficient energy conversion systems and will reduce solar power operating temperature to less than 100ºC.

1. Introduction

Energy, produced from conventional fuels like coal, oil, and natural gas is not environmentally friendly and causing serious global warming [11]. Apart from this, the availability of conventional fuels becomes a limiting factor due to raid industrialization and population growth. Renewable energy sources are very promising solutions for global warming [4, 5, 11, 12, 20]. Solar energy is considered to be the 'cleanest' and inexhaustible source of energy [4, 11]. Efforts [4, 11, 13, 15, 17, 21, 22] have made by many workers to transform solar energy into power. Power generation [13, 15, 17, 21, 22] from solar energy is primarily based on two main technologies: (i) photovoltaic and (ii) solar thermal. Photovoltaic systems [15, 17, 21] are widely employed for solar power generation. These systems depend directly upon the intercepting area of the solar radiation from the solar panel [11]. The other method of solar power generation based on thermal method [13, 15] that requires high operating temperature $(>400ºC)$ and gives low conversion efficiencies. The potential of solar energy is tremendous [11] that one hour insolation $(4.3 \times 10^{20} \, \text{J})$ on the earth can meet the entire energy demand of the earth $(4.1 \times 10^{20} \, \text{J})$. The amount of energy produced from the solar is very limited and its contribution to the society is not appreciable. It, therefore, requires a new approach for solar power generation that can boost its efficiency to increase its scope and promote the use of this renewable source of energy in to the society. Fuel cells are a promising energy source on account of their high efficiency and low pollutant emission and considered the best energy converter of the 21st century [1-3, 6-10, 14, 16, 18, 19]. It will be an attractive option to extend the scope of the "best energy converter" as available of today, i.e., fuel cell over the best energy potential "solar energy" to generate the solar power.

The fuel cell based on solar power generation may enable to harness the everlasting source of energy to overcome the present energy crisis. The working of fuel cells is based on chemical method of producing energy [16, 18]. There are various types of fuel cells [6, 16, 18] developed according to specific power output requirements. The details of the different fuel cells developed for various applications are summarized in Table 1. Proton exchange membrane (PEM) fuel cells have attracted considerable attention as a transport and portable power source for low operation temperature and rapid start-up [16, 18, 19]. Proton exchange membrane fuel cell (PEMFC) fits best to solar energy utilization [6] due to these two advantages associated with it.

Table 1. Different types of fuel cells

Details	PEMFC Proton exchange membrane FC	PAFC Phosphoric acid FC	MCFC Molten carbonate FC	SOFC Solid oxide FC	DMFC Direct methanol FC	AFC Alkaline FC
Working temp. (ºC)	70-90	150-200	600-650	700-1000	90-120	≤ 80
Electrolyte	Nafion	Phosphoric acid	Alkali carbonate	Yttria stablized zirconia	Nafion	KOH
Electrolyte state	Solid	Liquid	Liquid	Solid	Solid	Liquid
Charge carrier	H^+	H^+	CO_3^{2-}	O^{2-}	H^+	OH^-
Efficiency	70%	55%	55%	65%	30%	70%
Qualified power (W) upto	500kW	10MW	100MW	100MW	1MW	50kW

PEMFC [6] is a comparatively simple to design for 'solar gadgets' based on flat plate collector principle as it can be operated at relatively low temperatures (< 100ºC). It is easy to accumulate low temperature

solar heat by flat plate collector to operate fuel cell based solar power generation system. This new method of solar power generation [1, 10] utilizes coupling of chemical reactions (2-propanol / acetone / hydrogen) in the PEM fuel cell. The novelty of the present solar power generation based on PEM fuel cell (SOLARPEM) technique is that low grade solar heat (favourable for designing solar system) is sufficient to support the required chemical reactions (dehydrogenation/hydrogenation) involved in the generation of power from the solar thermal energy [6, 11]. Operating temperature in the novel solar power generation system is reduced to less than $100^{o}C$ compared to $400^{o}C$ required in conventional or 'traditional' solar concentrated power systems [10, 22]. The flat plate solar collector [11] is sufficient to collect low grade solar heat ($< 100^{o}C$) than concentrated solar system required in the solar thermal based system. The flat plate solar collectors are easy to fabricate, easy to maintain, and easy to operate compared to concentrated solar system.

In the SOLARPEM, a PEM fuel cell with specific electro-catalysts assisted by solar thermal energy is used to process chemical coupling and in turn generates solar power [10]. A chemical is dehydrogenated [2, 7] with electro-catalysts aided with solar radiation to evolve hydrogen. The hydrogen is then processed in the fuel cell to generate power. The proposed power generation system consists of various components: PEM fuel cell, dehydrogenation reactor, flat plate solar collector, and other associated components. The PEMFC unit being the heart of the solar power generation system has been developed at the Fuel Cell Laboratory, University of Birmingham, UK. The functioning of such a PEM fuel cell unit depends largely upon the catalytic activity of the electrodes employed to attain required efficiencies [18]. The study has been carried-out in this direction and presents the results on the PEMFC. The results are highly encouraging and power density has been achieved $2.06 mW/cm^2$ at a temperature $60^{o}C$. The study is continued to maximize power density for designing prototype "SOLARPEM" unit, which will effectively open the way to push the power generation from the solar energy.
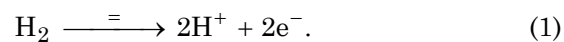
2. Fuel Cell

Fuel cells forgo the traditional system of heat combustion process to convert into energy [16]. It is an electrochemical conversion system, which converts chemical energy directly into electrical energy through electrochemical oxidation and reduction reactions [16, 18]. The basic parts of fuel cell consist of anode, cathode, and an electrolyte, where fuel is supplied at the anode and oxidant is supplied at the cathode. These two react in the presence of electrolyte, which is sandwiched in between anode and cathode electrodes. At the anode, hydrogen oxidation reaction takes place resulting in the production of electrons and hydrogen ions. At the cathode, oxygen is supplied, which along with electrons produced at anode and protons permeated through electrolyte (membrane) combine to form pure water.

2.1. Concept of regenerative fuel cell

The development of regenerative fuel cell is upcoming promising technology for the solar power generation [1, 7]. The production of the hydrogen (intermediate step of the SOLARPEM) from the 2-propanol using solar energy is used for the current generation. The hydrogen is used as fuel at the anode side and the oxidant used at the cathode side, which is a mixture of 2-propanol, acetone, and water. The mixture of 2-propanol, acetone, and water, which serves as an oxidant reacts in presence of catalyst and the output from the cathode side contains a mixture of 2-propanol and water and un-reacted acetone [1, 6, 7, 10]. The reactions taking place at anode and cathode side are as follows:
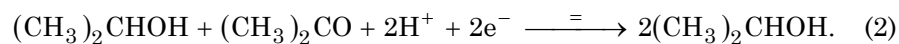
Reaction at catalytic anode

$$\text{H}_2 \xrightarrow{\text{Catalyst}} 2\text{H}^+ + 2\text{e}^-. \tag{1}$$

Reaction at catalytic cathode

$$(\text{CH}_3)_2\text{CHOH} + (\text{CH}_3)_2\text{CO} + 2\text{H}^+ + 2\text{e}^- \xrightarrow{\text{Catalyst}} 2(\text{CH}_3)_2\text{CHOH}. \tag{2}$$

The hydrogen ion, i.e., proton, which is exchanged by the nafion membrane (electrolyte) is available on the cathode side and in the presence of catalyst, it combines with acetone to form 2-propanol. The hydrogen is produced from the 2-propanol reactor under the action of catalysts and solar energy. The schematic diagram of the SOLARPEM (solar power generation based on PEM fuel cell technique) is depicted in Figure 1.
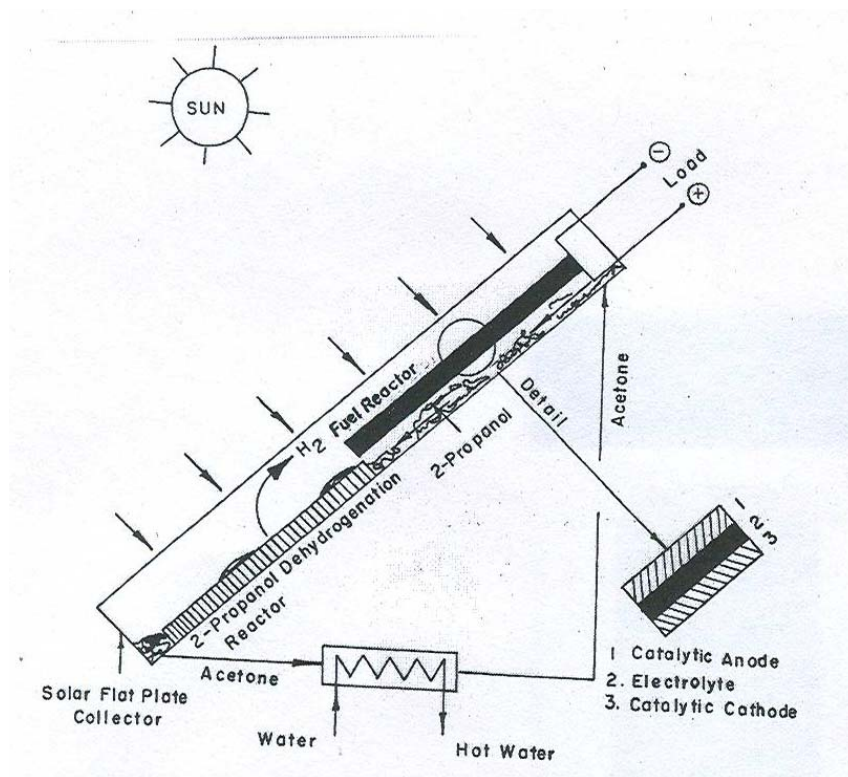

Figure 1. Schematic diagram of the solar power generation based on PEM fuel cell (SOLARPEM).

The concept of regenerative fuel cell arrives from the regeneration of fuel "hydrogen" from the 2-propanol, which is a catalytic reaction. The 2-propanol liberates hydrogen at 82ºC by the following reaction and the byproduct is acetone, which can then be fed back to the catalytic cathode side.

$$(CH_3)_2 CHOH \xrightarrow{\quad} (CH_3)_2 CO + H_2. \tag{3}$$
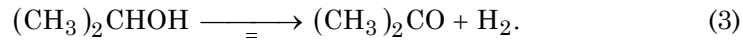
In this way, the only output of the system will be energy and hence the system is called as *regenerative fuel cell system*. This reaction is endothermic reaction, taking place nearly at a temperature of 82°C. The heat, with a temperature of about 82°C, can be easily obtained from a panel of a suitable flat plate solar collector system [11] to accomplish the above-mentioned reaction to generate electric power, and hence this system may also be referred as the "solar thermal fuel cell". The reactions taking place in the SOLARPEM are shown more clearly in the flow diagram in Figure 2. The application of such fuel cells in solar energy utilization has a bright future for generation of power through SOLARPEM (a new approach) and is entirely different from the photovoltaic system.
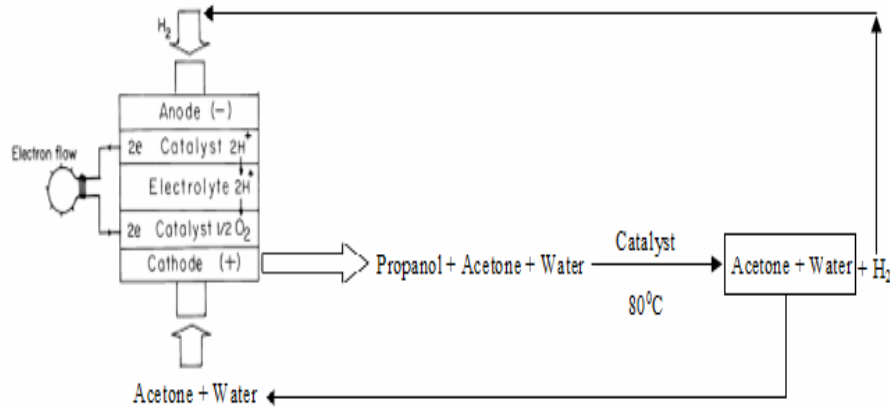

Figure 2. Flow diagram of the SOLARPEM for solar power generation.

2.2. Fuel cell hardware

Figure 3 shows a PEM fuel cell hardware fabricated from the scarab materials available in the Fuel Cell Laboratory, University of Birmingham, UK. This fuel cell hardware was used to test the various catalysts prepared in the laboratory. Two graphite plates (dimensions:

$9.5cm \times 9.5cm \times 1.2cm)$ were used in the fuel cell. The graphite plates had the groove facility of column flow for the hydrogen and the air/liquid oxidant (2-propanol + acetone + water). To collect current from the fuel cell, copper plates with golden polish (dimensions: $11cm \times 9.5cm \times 0.3cm)$ were used with the graphite plates in the fuel cell. The areas of column flow for both fluids (air/liquid oxidant) in the graphite plates were $25cm^2$ $(5cm \times 5cm)$. The silicon gaskets (silex make) of size $9.5cm \times 9.5cm$ were suitably used in between the graphite plates to keep insulated from each other. The thickness of the silicon sheet in the present study was 0.5mm. The membrane exchange assembly (MEA) was sandwiched in between the silicon sheets (gasket). The MEA active area was varied from $5cm^2$ to $12cm^2$ in the fuel cell. It was done with the help of the silex sheet using suitable grooving in between the graphite plates. The MEA consisted of the Nafion-112 / Nafion-115 (Dupont) of area $5cm \times 5cm$. The fuel cell was heated with Watson silicon rubber heaters on both sides of the golden plates. The sizes of the both silicon electric heaters were the same (dimensions: $5cm \times 5cm$). The steel tubes (length 6cm, OD 0.6cm, and ID 0.45cm) were used on both sides of the graphite plates for the flow of hydrogen and the air/liquid oxidant. In the study, the hydrogen was flown in the bottom side of the graphite plate and liquid oxidant or air in the upper side of the fuel cell. The experimental set-up for the testing the various combinations of catalysts in the Fuel Cell Laboratory, University of Birmingham, UK, is shown in Figure 4. Readymade MEAs were also tested in the present fuel cell hardware. The catalysts were tested under various conditions. The fuel cell was examined for its performance under different conditions with H_2/liquid oxidant. A peristaltic pump was used to monitor the flow rate of the inlet liquid oxidant and mass flow controller for monitoring the flow rate of the inlet fuel gas, i.e., hydrogen. Initially, the fuel cell was tested with hydrogen as fuel at the anode side and liquid oxidant at the cathode side with a view to maximize the current generation from the PEMFC. After maximizing the current generation from the PEMFC, the hydrogen will be used from the

2-propanol dehydrogenation reactor. A few catalysts developed at the Fuel Cell Laboratory, University of Birmingham, UK, were also tested at the Fuel Cell Laboratory, Indian Institute of Technology, New Delhi, India. The experimental set-up for testing the catalysts in the PEM fuel cell at the Fuel Cell Laboratory, IIT, India, is shown in Figure 5.
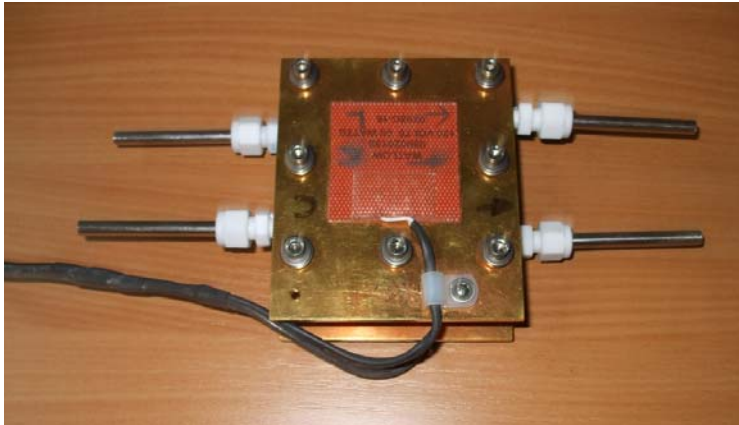

Figure 3. Assembled fuel cell at the workshop of the Fuel Cell Laboratory, University of Birmingham, Birmingham, UK.

Figure 4. Testing of PEMFC at the Fuel Cell Laboratory, University of Birmingham, Birmingham, UK.

Figure 5. Experimental set-up for testing PEMFC at the Fuel Cell Laboratory, Indian Institute of Technology, New Delhi, India.

3. Catalytic Electrodes

The reaction in the fuel cell depends upon the catalysts and plays a major role in its performance. For this purpose, catalytic electrodes were made by different methods in the Fuel Cell Laboratory, UK. The following methods were used to prepare the catalytic electrodes by using platinum and ruthenium in the various loadings:

(i) Impregnation method (reduced with H_2 and N_2).

(ii) Printing method (by making catalytic ink).

The loadings of the catalysts were calculated according to requirements to deposit on the substrates. The loading calculations of a composite catalysts Pt and Ru prepared from the precursors $H_2PtCl_6.6H_2O$ and $RuCl_3.3H_2O$ over a carbon cloth is given in Table 2. In Table 2, the loadings for both catalysts (Pt and Ru) are 15%. The catalysts from the precursors were deposited on two types of substrates for making the catalytic electrodes. The substrates used to deposit the pure and composite catalysts are as follows:

(i) Zorflex activated carbon cloth FK 30K.

(ii) GDL LT 1200W.

Table 2. Loading calculation of platinum and ruthenium catalysts on carbon cloth

Example			
Basis	Carbon cloth (1mm)	Pt + Ru	Pt + Ru/carbon cloth
Say for 15%Pt and 15%Ru	1.000gm	0.150gm + 0.150gm	1.300gm

Procedure	
15%Pt from precursor $H_2PtCl_6.6H_2O$ on carbon cloth	
Weight of carbon cloth (6.5cm $\times$ 6.0cm)	= 470mg
Area of carbon cloth	= 39cm^2
Amount of precursor required for loading	
Pt loading required = 470mg $\times$ 0.150	= 70.5mg
MW of $H_2PtCl_6.6H_2O$	= 517.90
MW of Pt	= 195.08
Amount of precursor : 70.5 = 517.90 : 195.08	= 187.1mg
Used 8% CP solution (dissolved 80mg CP acid in 1ml water	
Vol. of CP acid = (187.1 /80) = 2.338ml	

15% Ru Pt from precursor $RuCl_3.3H_2O$ on the same carbon cloth	
Weight of carbon cloth (6.5cm $\times$ 6.0cm)	= 470mg
Area of carbon cloth	= 39cm^2
Amount of precursor required for loading	
Ru loading required = 470mg $\times$ 0.150	= 70.5mg
MW of $RuCl_3.3H_2O$	= 216.47
MW of Ru	= 101.07
Amount of precursor : 70.5 = 216.47 :101.07	= 182.3mg

Deposited Pt and Ru on carbon cloth by impregnation technique.

A few catalysts (pure and composite) with different loadings on the substrates prepared in the Fuel Cell Laboratory, UK, are given in Tables 3, 4, and 5. These catalysts were investigated in the PEM fuel cell hardware under various conditions with a view to evolve the best configuration of the catalysts for the current generation.

Table 3. Pure Pt catalysts loaded on carbon cloth from precursors $H_2PtCl_6.6H_2O$ and K_2PtCl_4

S. No.	Catalysts	Composition	Loading of catalyst mg/cm^2	Precursors
1	Pt	Pure	0.602	K_2PtCl_4
2	Pt	Pure	0.812	K_2PtCl_4
3	Pt	Pure	1.389	K_2PtCl_4
4	Pt	Pure	2.134	K_2PtCl_4
5	Pt	Pure	2.989	K_2PtCl_4
6	Pt	Pure	0.624	$H_2PtCl_6.6H_2O$
7	Pt	Pure	0.954	$H_2PtCl_6.6H_2O$
8	Pt	Pure	1.288	$H_2PtCl_6.6H_2O$
9	Pt	Pure	1.879	$H_2PtCl_6.6H_2O$
10	Pt	Pure	2.451	$H_2PtCl_6.6H_2O$

Table 4. Composite Ru and Pt catalysts made from precursors $RuCl_3.3H_2O + K_2PtCl_4$

S. No.	Catalysts	Composition	Loading ratios mg/cm^2	Precursors
1	Ru + Pt	Composite	0.655 + 0.326	$RuCl_3.3H_2O + K_2PtCl_4$
2	Ru + Pt	Composite	0.996 + 0.331	$RuCl_3.3H_2O + K_2PtCl_4$
3	Ru + Pt	Composite	1.278 + 0.319	$RuCl_3.3H_2O + K_2PtCl_4$
4	Ru + Pt	Composite	1.640 + 0.326	$RuCl_3.3H_2O + K_2PtCl_4$
5	Ru + Pt	Composite	2.004 + 0.333	$RuCl_3.3H_2O + K_2PtCl_4$
6	Ru + Pt	Composite	0.639 + 0.639	$RuCl_3.3H_2O + K_2PtCl_4$
7	Ru + Pt	Composite	0.994 + 0.622	$RuCl_3.3H_2O + K_2PtCl_4$
8	Ru + Pt	Composite	1.319 + 0.657	$RuCl_3.3H_2O + K_2PtCl_4$
9	Ru + Pt	Composite	1.626 + 0.650	$RuCl_3.3H_2O + K_2PtCl_4$
10	Ru + Pt	Composite	1.828 + 0.609	$RuCl_3.3H_2O + K_2PtCl_4$

Table 5. Composite Ru and Pt catalysts made from precursors $RuCl_3.3H_2O + H_2PtCl_6.6H_2O$

S. No.	Catalysts	Composition	Loading ratios	Precursors
1	Ru + Pt	Composite	1.807 + 1.807	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
2	Ru + Pt	Composite	0.968 + 0.617	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
3	Ru + Pt	Composite	1.342 + 1.116	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
4	Ru + Pt	Composite	1.347 + 1.681	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
5	Ru + Pt	Composite	1.890 + 1.681	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
6	Ru + Pt	Composite	1.789 + 1.789	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
7	Ru + Pt	Composite	2.129 + 1.566	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
8	Ru + Pt	Composite	1.205 + 1.205	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
9	Ru + Pt	Composite	2.782 + 1.867	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$
10	Ru + Pt	Composite	1.780 + 2.562	$RuCl_3.3H_2O + H_2PtCl_6.6H_2O$

4. Experiment and Results

The PEMFC was first tested for its performance with the hydrogen as fuel at the anode side and oxidant at the cathode side for the standardization of flow rate of inlet fuel gas. It was found [9, 10] that hydrogen with flow rate at 15ml/M had given the better results for current generation. This flow rate of hydrogen was chosen in the present study for the current generation at various concentrations of the liquid oxidant. In the present study for maximizing the power density from the PEMFC, the hydrogen was used from the grid supply of the laboratory. After optimizing the power density from the PEMFC, the hydrogen will be produced within the SOLARPEM by using 2-propanol reactor (see Figure 1). The study of the PEM fuel cell was made at different flow rates of liquid oxidant from 0.50ml/M to 1.0ml/M. It was observed that better results were obtained with the flow rate of liquid oxidant at 0.74ml/M. The investigations were made for current generation of the PEMFC with different catalysts with these chosen flow rates of hydrogen at 15ml/M and liquid oxidant flow rate at 0.74ml/M. It was found that the catalysts loading with 2.0mg/cm^2 (platinum + ruthenium catalysts) at the anode side and 4.0mg/cm^2 at the cathode side has yielded comparatively better performance for the current generation from the PEMFC. A detailed study was made with this configuration of the catalysts in the PEMFC under different conditions with a view to obtain maximum power density. To maximizing the power density from the PEMFC, the concentration ratios of the liquid oxidant (2-propanol : acetone : water) was varied from 1:3:94 to 9:6:85. A few results of the power density obtained from the PEMFC at different concentration ratios of the liquid oxidant (different mixtures of the constituents of the liquid oxidant) are given in Table 6. The Table 6 shows that PEMFC has given the maximum power density 2.06mW/cm^2 with liquid oxidant ratio 6:6:88 (2-propanol : acetone: water). When the concentration of the 2-propanol in the liquid oxidant was increased beyond 6%, the power density from the PEMFC was found to

reduce. In this study, the hydrogen flow was at the bottom side of the PEMFC and liquid oxidant was on the top side of the PEMFC. The performance study of the PEMFC was also made in reversed position, i.e., the PEMFC was reversed with upside down. The flow of the hydrogen was on the top side of the PEMFC and liquid oxidant at the bottom side of the PEMFC. The performance of the PEMFC was similar in both conditions. The study of the temperature effect on the output of the PEMFC was also carried-out. For it, the investigations for current generation from the PEMFC were made in the temperature range from $35^{o}C$ to $60^{o}C$. The temperature of the fuel cell was increased with the help of Watson silicon rubber electric heater attached with the outer plates of the PEMFC. The temperature was increased in an interval of $5^{o}C$. The power density from the PEMFC was found to increase with the temperature and the results are reported in Table 7. At the temperature $35^{o}C$, the power density was $0.71 mW/cm^2$, which was found to increase to $2.06 mW/cm^2$ at $60^{o}C$. It shows that, with the same set of catalysts configurations and the same flow rates of hydrogen and liquid oxidant, the power density of the PEMFC increased almost by three times. The temperature $60^{o}C$ can easily be achieved by the flat plate solar collector, when the prototype SOLARPEM is designed for the solar power generation. For a given temperature and flow rates of fuel/liquid oxidant, the investigations for the performance of the PEMFC were repeated for a few cycles under similar conditions. It was observed that the performance of the PEMFC was found to decrease slightly with the repeated cycles.

Table 6. Performance of PEM fuel cell with different mixture combinations of the liquid oxidant

S. No.	Temperature (°C)	Mixture of liquid oxidant (2-propanol + acetone + water)	Power density (mW/cm²)
1	60	1:3:96	1.32
2	60	3:3:94	1.53
3	60	6:3:91	1.82
4	60	6:6:88	2.06
5	60	9:6:85	1.98

Loading at catalytic anode: 2.0mg/cm² (Pt + Ru).

Loading at catalytic cathode: 4.0mg/cm² Pt.

Flow rate of hydrogen: 15ml/M.

Flow rate of mixture liquid oxidant (2-propanol + acetone + water): 0.74ml/M.

Hydrogen flow at bottom of the fuel cell.

Liquid oxidant flow on the top side of the fuel cell.

Table 7. Performance of the PEM fuel cell based on 2-propanol/acetone/H_2 at different temperatures

S. No.	Temperature (ºC)	H_2 flow rate (ml/M)	Liquid mixture oxidant flow rate (ml/M)	Power density (mW/cm²)
1	35	15	0.74	0.71
2	40	15	0.74	1.21
3	45	15	0.74	1.32
4	50	15	0.74	1.48
5	55	15	0.74	1.80
6	60	15	0.74	2.06

Loading at catalytic anode: 2.0mg/cm² (Pt + Ru).

Loading at catalytic cathode: 4.0mg/cm² Pt.

Mixture of liquid oxidant (2-propanol + acetone + water): 6:6:88.

Hydrogen flow at bottom of the fuel cell.

Liquid oxidant flow on the top side of the fuel cell.

To study the surface morphology of the catalytic electrodes employed in the PEMFC, SEM analysis was carried-out before and after the experiments. For the catalysts on the anode, the SEM picture was taken before and after the experiments. The Figure 6(a) shows the SEM analysis on the anode before the experiment, which gave a clear picture of the fibers. The SEM picture for the anode after the experiment is shown in Figure 6(b). The deformation of the fibers was observed after the experiment (see Figure 6(b)).
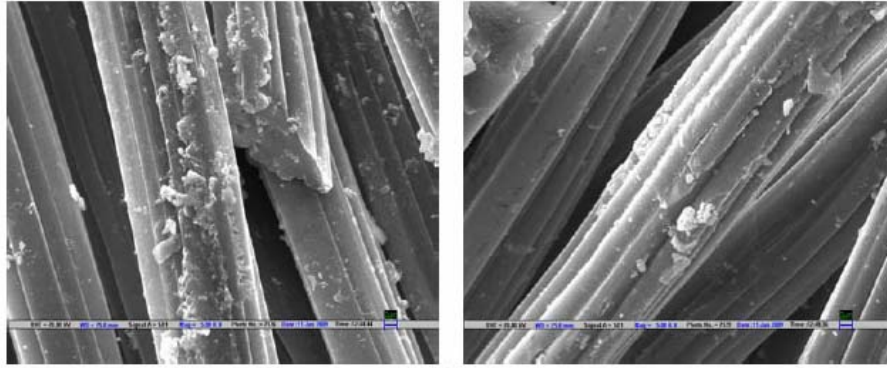
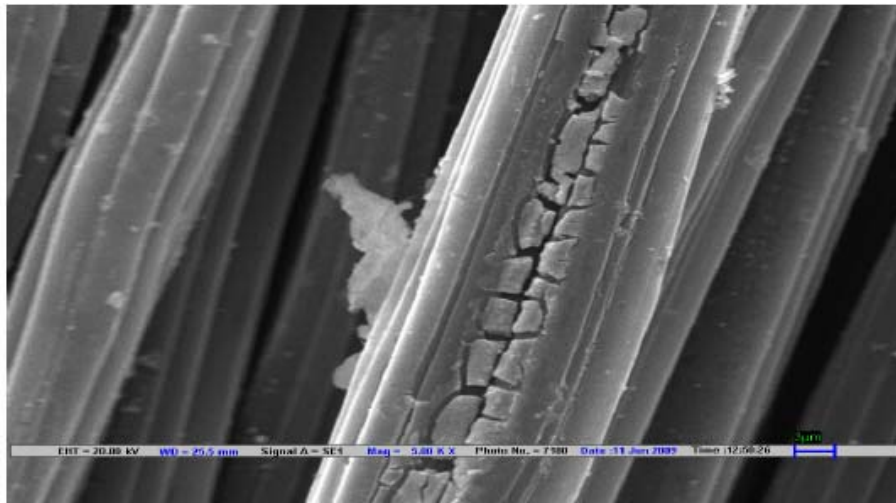**Figure 6(a).** SEM analysis of the anode catalyst sample before the experiment.

Figure 6(b). SEM analysis of the anode catalyst sample after the experiment.

The deposition of the catalyst particles was clearly observed on the fibers of carbon cloth before the experiment. After the experiment, some deformations of the fibers were observed that may lead to decrease in the performance of the PEMFC. Some deformations, after the experiment, were also observed on the cathode side catalysts as shown in Figure 7. The Figure 7 shows some depositions of the products formed or some

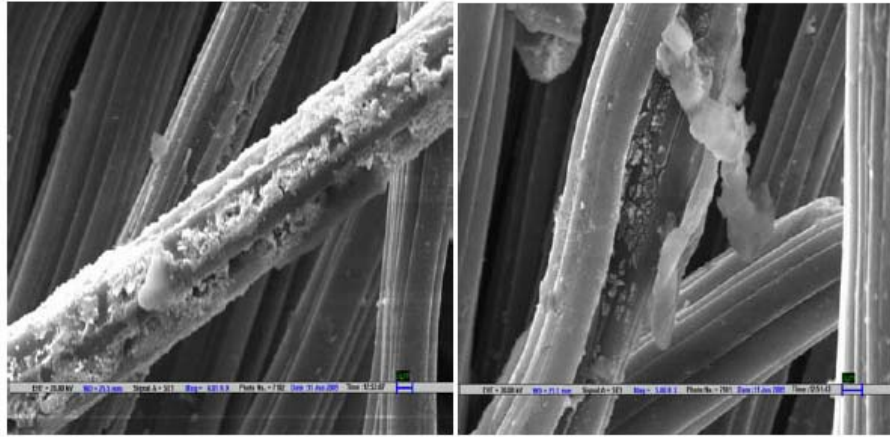intermediate products on the fibers, which may also hamper the performance of the PEMFC.

Figure 7. SEM analysis of the cathode catalyst sample after the experiment.

5. Conclusion

(1) The best combination of anode side catalyst with a loading of 2.0mg/cm^2 (platinum + ruthenium) and cathode side catalyst with loading of 4.0mg/cm^2 yielded better performance of the PEMFC.

(2) Power density has been found to increase with temperature. It increased to almost three times when the operating temperature was increased from 35°C to 60°C.

(3) Maximum power density 2.06mW/cm^2 has been achieved from the PEMFC.

(4) Liquid oxidant with mixture ratios of 6:6:85 (2-propanol + acetone + water) has given higher power density for a given flow of hydrogen at 15ml/M and liquid oxidant flow at 0.74ml/M.

(5) The power density from the PEMFC was found to decrease slightly with subsequent repeated cycles.

(6) SEM analysis results confirm the deformation of the carbon fibers and also the deposition of some intermediate products on the cathode side catalyst after the experiment.

Work is continued to maximizing the power density from the PEMFC for appreciable solar power generation, when the prototype SOLARPEM is designed.

Acknowledgement

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