Effect of Hydrophobisation on the Performance of Conventional PEM Fuel Cell

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Abstract – **Membrane electrode assembly is the heart of the fuel cell. So optimizing the properties of the membrane electrode assembly i.e. both the anode and cathode is important. In this paper aims in finding the optimum percentage of hydrophobisation of the electrodes in order to have the improved performance of the air breathing and conventional PEM fuel cell. The phenomenon of the conduction of the protons and the passage of the oxygen between the electrodes is greatly influenced by the constituents of the membranes and the electrodes. Thus the performance of the membrane electrode assemblies in the fuel cell was determined by plotting out their respective current density and power density curves. The best combinations among the MEA's produced were identified. They are 10% cathode hydrophobised MEA for conventional type with a peak power density of 162 mw/cm^2.**

Keywords: Air breathing, Anode, Cathode, hydrophobised, Membrane electrode assembly

I. INTRODUCTION

A fuel cell is a device that converts a fuel stream directly into electrical power. First significant applications was in the U.S space program starting in 1960s, for space applications fuel cell technology offered electricity generation and water production using hydrogen and oxygen gas. In the mean time fuel cell for stationary power generation was also being developed. Fuel cell technology is attractive for vehicle propulsion, offering low emission and a level of efficiency competitive with the best of reciprocating engine technology. There are several fuel cell technologies, all of which use a different electrolyte.The technology most likely to be used in vehicle applications is the proton exchange membrane fuel cell (PEMFC). PEMFC is one of the most promising candidates for future power generation in transportation, stationary and mobile applications. In small scale applications, the fuel cell should be small and high energy density [1], while battery technology has improved considerably in recent years, the functionality, operating speed and lifetime of many portable devices are still limited in how long they can operate as truly portable (i.e. unplugged) devices by the quantity of energy that can be stored within them, fuel cells however provide significant advantages over conventional battery systems [2]. Interest in using fuel cells to power portable equipment for commercial applications is relatively recent. This is perhaps partly due to the success of Li based batteries in powering laptop computers, mobile phones and the like. The requirement for high energy density, higher specific energy or longer operational time between recharges was generally well served by the LI-ion battery and nickel-based batteries especially those based on metal hybrids. Safety and environmental factors were key considerations in addition to the high energy density of these batteries [3].

The main advantages are
- the flexibility with respect to power and capacity achievable with different devices for energy conversation and energy storage,
- the long time and long service life,
- the good ecological balance,
- Very low self discharge [4].

Most fuel cell research targets stationary premium power and automotive applications and stacks capable of delivering approximately 1-200 kW. The large cells are typically mechanically compressed sandwiches of graphite composites electrodes and membrane assemblies. To create a miniature fuel cell for portable devices that delivers power in the range of 0.5-20W, one will not achieve an optimum design by simply scaling down the larger system. Rather, one must redesign each component of the fuel cell with an eye towards miniaturization [2].

II. PREPARATION OF MEMBRANE ELECTRODE ASSEMBLY

Carbon sheets where used as the base material for electrodes, both anode and cathode. Eight electrodes of 25 cm^2 each (5 cm x 5 cm) were cut for the air breathing type. In order to do hydrophobise or teflonise the carbon sheet, the carbon sheet must be treated with the Teflon solution (Fig 1).
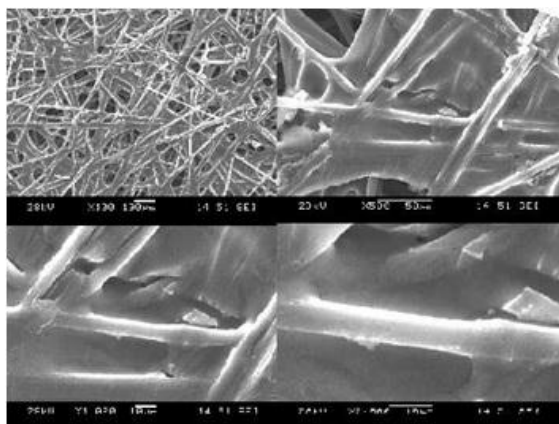
Fig 1. SEM images for hydrophobised cathode before sintering at resolutions of 100X, 500X, 1000X and 2000

The electrodes after hydrophobisation were sintered in a muffle furnace. The sintering temperature is slightly kept below the melting point of Teflon. The electrodes were sintered at the temperature of 280°C and 350°C for 15 minutes each. The Teflon added to the electrodes will be over the fibers which are not adhering to it properly.

A. Catalyst Ink Preparation
The catalyst ink is prepared depending upon the area of the electrodes. Here the catalyst used is 20% platinum on carbon powder. The constituents of catalyst ink are:
1. Catalyst - Platinum on Carbon powder.

2. Solvent – n-propyl alcohol.

3. Nafion solution.

4. Distilled water.

In this the calculated amount of catalyst is weighed and water was added in order to wet all the molecules of the catalyst. Water was carefully added to the correct quantity which ensures that the catalyst turned into a semisolid paste rather than becoming a liquid solution. In this the calculated amount of catalyst is weighed and water was added in order to wet all the molecules of the catalyst. Water was carefully added to the correct quantity which ensures that the catalyst turned into a semisolid paste rather than becoming a liquid solution. This paste is stirred well using the glass stirrer so that there is no more catalyst powder which has not been wetted. Addition of nafion solution in the catalyst ink is very essential as it enables the most vital activity of proton ion conduction between the nafion membrane and the electrodes. 5% Nafion solution stored at a cold temperature of about 10°C is added to catalyst paste in the correct quantity using a measuring beaker. The nafion solution is not directly poured into the catalyst paste as the platinum present may bring harm to the purity of the nafion solution. n-propyl alcohol which is the solvent was added finally to the catalyst. After the ink has been produced it has to be kept in a closed container since the solvent evaporates. 1-propanol was sometimes added in the later stage to compensate for its loss due to its evaporation.
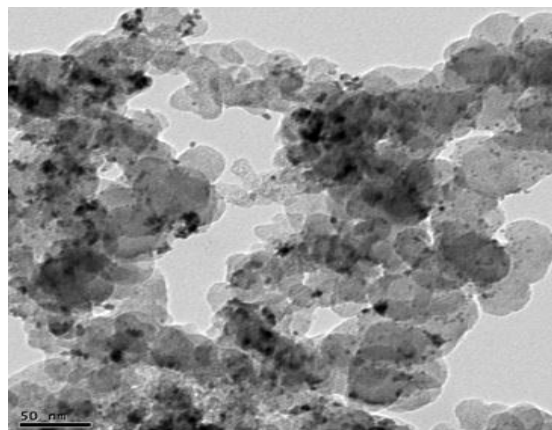

Fig 2. SEM image of catalyst showing the platinum on carbon powder

Sonification is done for 60 minutes at an interval of 15 minutes. It is done for atomic level mixing of catalyst to take place. It's a method in which ultrasonic waves is passed to the catalyst ink which is kept in the water bath in order to bring in fine mixing of all ingredients of catalyst ink even at molecular level. After Sonification the catalyst ink is sprayed over the electrodes which are placed over a rigid base. Nitrogen gas at a pressure of 1.5 kg/cm2 was used to spray the catalyst ink over the electrode using a spray nozzle. After spraying the catalyst ink over the electrodes, they are dried at the temperature of 60°C. A over head blower was used to suck the evaporating solvent while spraying to ensure healthy working conditions. Then the electrodes are checked for the weight gain. The membrane used is Nafion – 117. The digit 7 indicates the thickness of the membrane in mills. First the membrane is put in the boiling water for 60 minutes. The membrane is rinsed and the treated in a solution containing 100 ml of hydrogen peroxide and water which is made upto 1000 ml. this treatment is done at 70°C for 60 minutes. Then the membrane is rinsed twice with deionised water. Then a solution of 1000ml was prepared containing 30 ml of sulphuric acid and remaining amount is water. The membrane is put in that solution for 60 minutes and at 70°C.this is done in order to activate the sulphonic group in the nafion polymer. This membrane was again washed twice in water and put in a beaker containing deionised water. This membrane with water in a beaker was stored in dark place. Now the electrodes are prepared and the membrane is treated and it is ready for the assembly. Insert the membrane between the two electrodes like the sandwich. MEA is now covered with the butter paper and it is kept between the plates of the hot press at 130°C. The MEA was pressed by applying a pressure in the range of 1 -2 kg/cm^2 for 3 minutes and after this the MEA was removed and then allowed to cool below 100oC, till then do not take the MEA out.

III CONVENTIONAL FUEL CELL

A. Membrane electrode assembly (MEA)
The prepared MEA is being used in this experimental setup (Fig 3).

B. Teflon sheets

Teflon sheets as shown in figure are placed on both sides of the MEA to compensate the thickness of the electrode. This addition of Teflon sheets avoids the formation of gap in the fuel cell assembly between the electrodes and the MEA thus establishing proper contact between the electrodes and the flow channels and also prevents any leakage of hydrogen during the course of its operation (Fig 4).
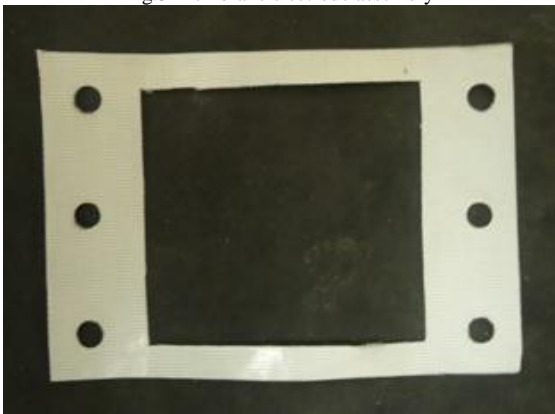

Fig.3 Membrane electrode assembly

Fig.4 Teflon sheets

C.Graphite plates

The graphite plates consist of the required flow channels through which the reactant gases flow. The anode side graphite plate consists of serpentine type flow channels through which the hydrogen from the cylinder flows through. Since the hydrogen gas comes in contact with the electrode for longer time in serpentine type of flow channel it has been preferred over the other types. Here 1mm x1mm serpentine flow channels are milled on the anode side to an area of 25 cm^2.The cathode side graphite plate consists of parallel ducted type flow channels through which the atmospheric oxygen comes in contact with the cathode. The water formed on the cathode side is also made to move through these ducts. Here 6mm x 6mm parallel flow channels are milled on the cathode side. Flow of oxygen on the side of the cathode is by free convection only. So channels are machined throughout the length of the plate (Fig 5&6).
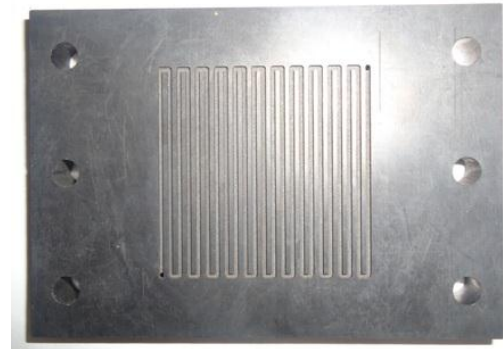

Fig.5 Graphite plate (Anode)

Fig.6 Cathode side graphite plate having parallel ducted flow channel

D.Copper plates

The copper plates with the same dimension as that of the graphite plates is used with an extra projection at its top corner for current collection. Proper contact has to be established between the copper and graphite plates on both the sides of the cell (Fig 7).

Fig.7 Copper plates

E.Aluminium endplate and connectors

For the supply of hydrogen, two tapped holes are machined to insert the connector in the Aluminium plates. Aluminium plate is used on the anode side to which connectors are connected. These connectors enable the flow in and flow out of the hydrogen gas. While assembling the Aluminium plate also provides better support to the fuel cell assembly. The assembly of the MEA, Teflon sheets, graphite plates, copper plates and the Aluminium plates is fastened using the bolts (Fig 8).
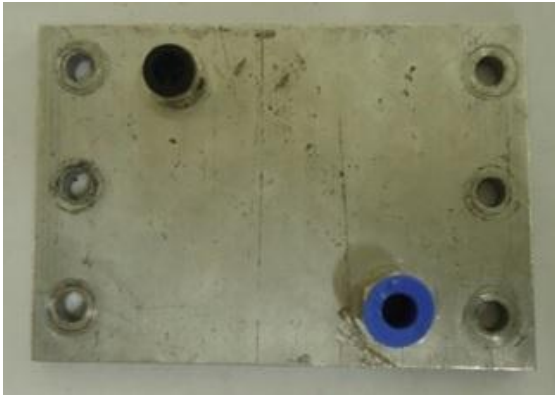
Fig.8 Aluminium plate with connectors.

IV CONVENTIONAL TYPE FUEL CELL EXPERIMENTATION

The tube which supplies oxygen is connected to the cathode side supporting plate and the tube which supply hydrogen is connected to the anode side supporting plate. The two pairs of wire are connected to the cell one for applying current and another for measuring the voltage developed. All the three cylinders are opened and set to 6 bar pressure. The test system was controlled by computer interfaced through software. The cell temperature, electrode temperature and the flow rate values were given to the software as input to set the fuel cell. The input of increments in load and the time interval were given by a program to the software. The polarization curve is directly generated by the software (Fig 9).
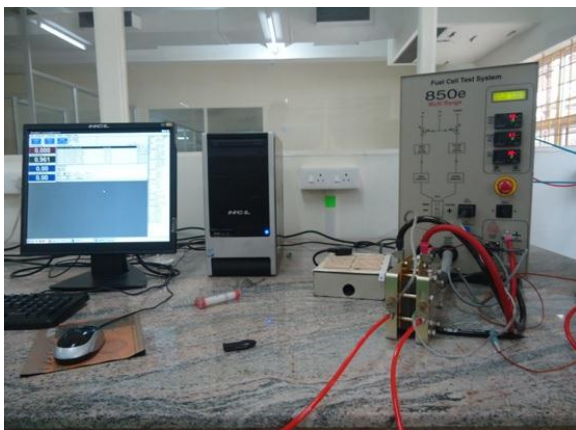

Fig.9 Experimental setup

Experiment	I	II	III
anode	10%	10%	10%
cathode	10%	30%	60%
Max power density (mw/cm^2) (load (mA))	28 (2000)	21.44 (2400)	36 (2400)
Cell temp (˚C) (load(mA))	30.8 (2800)	33.8 (3300)	34.2 (2800)

TABLE NO: 1 Experimenting Data

V RESULTS AND DISCUSSIONS

The MEA with 60% hydrophobisation on the cathode side has the lowest peak power density and it also withstands lesser loads than the other two electrodes. This can be due to reduction in the porosity of the cathode due more addition of Teflon which eventually leads to concentration losses. The MEA with 30% hydrophobisation on the cathode side has a peak power density slightly lesser than that of the MEA with 10% hydrophobisation on the cathode side. If used for stationary fuel cell systems both the MEA's has the same performance. Among the three curves plotted above the MEA with 10% hydrophobisation on the cathode side has the maximum peak power density of 162mV. Thus it is more suited for practical applications than the other two MEA's (Fig 10).
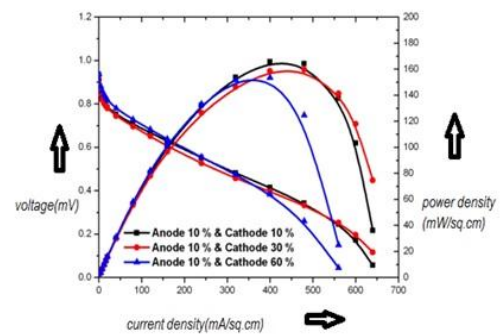

FIG.10 Combined current density curves for all three types all MEA prepared

VI CONCLUSION

A method has been devised for the preparation of membrane electrode assembly and seven membrane electrode assemblies has been produced and tested using this method. Three membrane electrode assemblies with an active area of 5cm2 and a platinum loading of 1 mg/cm2 was produced with varying percentage of hydrophobisation was produced for conventional type fuel cells using Nafion 117 polymer membrane and carbon sheets . The experiments conducted using these membrane electrode assemblies showed that the one with 10% hydrophobisation on the cathode side is more suited for practical applications as it has the maximum peak power density among the three membrane electrode assemblies produced

VII. REFERENCES

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