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Design and Operating Parameters on the Performance of Planar and Ducted Air Breathing PEM Fuel Cell

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Abstract

Water management is a burning issue in Air Breathing Fuel Cells (ABFC). Flooding and dehydration are the two main degradation mechanisms that occur when water management is not adequate. In this paper, experimental studies on air breathing fuel cell with ducted and planar design on cathode side were studied, including experiments with three different ratios of cathode open area with each design, varying the channel dimensions in the ducted design and varying the current collecting and the open area in the planar design. In ducted design the mass transfer limitations and flooding can be reduced with wider channels, where as in planar design larger opening area reduce the mass transfer limitations however wide channels require a rigid gas diffusion backing with current collecting ducts. The effect of varying hydrogen flow rate, various cell orientations, various ambient temperatures of both ducted and planar designs were compared.

Keywords: Air Breathing Fuel Cells, Ducted Design, Planar Design, Water Management

1. Introduction

Fuel cells are electrochemical devices that convert chemical energy into electricity and heat. They offer an alternate form of energy production that is environmentally friendly and can reduce dependency on fossil fuels. However, for the fuel cell system to become a viable commercial product, performance needs to be improved, the life of a cell needs to be extended, and total cost needs to be reduced.

Air breathing PEM fuel cell use free convection air flow to supply oxygen to their cathodes and hydrogen to anode from compressed gas cylinders. Free convection and diffusion are the primary transport mechanism for delivering oxygen to the cathode of air breathing fuel cell. Free convection air breathing fuel cells are characterized by low power density when compared to forced convection fuel cells but air breathing fuel cells are attractive for commercialization especially in portable electronic devices and transportation applications as the free convection oxygen delivery can eliminate auxiliary fan or compressor (air circulating device) as in forced convection fuel cells. Also weight and volume can be considerably reduced and safer to use hydrogen with air than with oxygen.

Air breathing fuel cells have their cathode directly exposed to the ambient air. Since the mass transfer at the cathode by free convection is due to concentration gradient and density gradient, the performance of an air breathing fuel cell is highly affected by the ambient conditions including relative humidity, ambient temperature, cell orientation etc. Since the performance of the air breathing fuel cell is sensitive with the ambient conditions, the area of the cathode opened to the ambient plays a vital role in the performance. The air flow and thus also the oxygen supply through natural convection and the water removal from the cathode and in the channels are proportional to the temperature and relative humidity difference between the cell and the surrounding air.

In an air-breathing PEM fuel cell, air supply at the cathode occurs by buoyancy induced natural convection

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flow due to temperature and concentration gradients. The cathode design is expected to affect the cell performance significantly as the buoyancy induced flow will be affected by the type of design used. Two types of cathode designs that are commonly used are ribbed (planar) and ducted (channel). Running PEMFCs in free convection mode significantly reduces the number of subsystems required. Absence of direct control over the air stream in the PEMFC makes temperature and humidity control an important problem. Infact, air breathing fuel cells consistently achieve lower performance than cells operated under forced convection mode. Many studies have been conducted on fuel cells running in free convection mode, either through modeling or experimentation. Main conclusions are that in this operation mode, problems limiting performances are due to mass transport and water management. Also, the importance of the surrounding conditions is highlighted.

There are two types of cathode superstructure namely ducted and planar. The effect of cathode structure on the performance of planar free breathing fuel cell is studied. While using in portable electronic devices the cell orientation and ambient conditions may affect the performance of the air breathing fuel cell, the effect of orientation of the air breathing fuel cell will not significantly affect the performance, but vertical orientation will better than horizontal orientation. Studies on various ambient conditions including RH and ambient temperature were studied and have significant effect on the performance in long term operations.

In this paper, experimental studies on air breathing fuel cell with ducted and planar design on cathode side were studied, including experiments with three different ratios of cathode open area with each design, varying the channel dimensions in the ducted design and varying the current collecting and the open area in the planar design. In ducted design the mass transfer limitations and flooding can be reduced with wider channels, where as in planar design larger opening area reduce the mass transfer limitations however wide channels require a rigid gas diffusion backing with current collecting ducts.

The cathode structure with few air openings yields low electrical losses but substantial mass transport losses. The lateral diffusive mass transport and lateral electrical transport should set an optimal criterion for the % open area in air breathing fuel cell cathode.

The effect of varying hydrogen flow rate, various cell orientations, various ambient temperature, dynamic response and longtime operation of both ducted and planar designs were compared. The study of various cell orientation implied convective mass transfer limitation. The mass transfer limitations caused by liquid water saturation in long term measurements may not be critical in real small scale applications.

2. Experimental Setup

Experiments were conducted using MEAs fabricated at Fuel Cell laboratory, PSGIAS[3]. The active area of the MEA is 25 cm^2 with a Pt/C (40%) catalyst loading of 1 mg/cm^2 (both anode and cathode) and 20% Hydrophobisation on anode side and 30% Hydrophobisation on the cathode side. The electrolyte membrane used is Nafion – 117. The assembled single cell is shown in Figure 1[4].

The fuel cell test station used for conducting the experiments is shown Figure 2. The test station used is Model 850e Compact Fuel Cell Test System (Scribner Associates, USA). The fuel cell test station consists of the following primary components: Fuel cell load, Temperature controllers for the cell and humidifiers, Heated/Insulated gas lines, Humidifiers, Mass flow controllers, Computer with data acquisition card and USB converter[2]. The

Figure 1. Assembled single ABFC.

Figure 2. Fuel Cell Test Station.

850e Compact Fuel Cell Test System contains humidifiers which forms the integral part of the fuel cell setup is placed inside the fuel cell[1]. The mass flow rate of the reactants is controlled by the mass flow controllers[5]. The heating rods are provided which allows fuel cell to control the cell temperature. The control and monitor of all the process is carried out by the software by integrating with the data acquisition card with suitable hardware components[6].

Hydrogen, supplied from a pressurized cylinder, is metered and routed through the heated anode humidifier before being fed to the anode side of the fuel cell. Oxygen supply to the cathode of the fuel cell happens by natural convection process due to the temperature and concentration gradients that exist in the fuel cell. Humidification of the feed stream at anode is necessary to maintain conductivity of the electrolyte membrane, especially at higher operating temperatures[7]. The desired volumetric flow rates for anode and cathode feeds are controlled by Mass Flow Controllers (MFC).Temperature of the cell was measured using an RTD.

An inert gas such as nitrogen (N_2) is used to purge the anode and cathode chambers of the cell prior to introducing reactants and prior to shutting down the cell. The intent of the former is to prevent mixing the O_2 present within the anode compartment after assembling the cell with H_2 which is potentially dangerous and can cause corrosion on the anode components[8]. Purging with nitrogen prior to the shutdown is also a safety measure to flush the residual H_2 from the cell. Heating of the humidifiers, the tubes leading to the fuel cell, and preheating of the fuel cell is accomplished using heating tape. The temperature of the feed streams and fuel cell are maintained using temperature controllers. To avoid flooding the cathode, the humidifier temperature controlled polished metal surface and measuring its dew point commercial dew point and humidity sensors are available[9].

During a typical experimental run (constant flow rate, oxidant composition, and temperature), the current is manipulated/adjusted on the fuel cell load and the voltage and resistance are recorded from built-in meters in the load[10]. The fuel cell load uses the current –interrupt technique to measure the total ohmic resistance between the voltage sense leads, which includes and electronic resistances and all contact resistances. These processes are monitored automatically and controlled by the computer using Fuel Cell software[11].

3. Results and Discussion

The planar (a) and ducted (b) cathode designs used for the study are shown in Figure 3[12]. Anode flow channel was machined on 10mm thick graphite plate. Single serpentine channel with 1mm X 1mm channel dimension was machined on the graphite plate for hydrogen flow[13]. Two different designs (Planar and Ducted) were used for cathode flow field plate. The different duct dimensions studied with ducted design and the different open areas studied for the planar design are listed in Table 2[14]. The current collector plates used were silver coated copper plates[15].

3.1 Effect of Duct Dimensions

The different duct dimensions are studied with ducted cathode design as shown in Table 1[16]. Experiments are conducted at the Dead End Mode (DEM), where the exit of hydrogen is closed and at 0.1 LPM and the observations are as shown in Figure 4 and 5[17].

At the Dead End Mode (DEM) it is inferred that higher the hydraulic diameter of the duct - better the performance.

Even when the hydrogen is allowed to flow at 0.1 LPM, it is observed that performance is higher at higherhydraulic diameter[18].

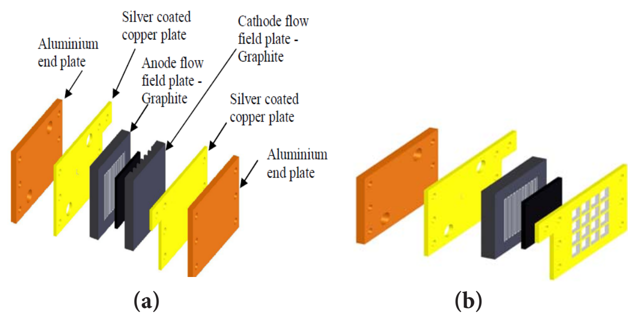
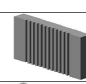
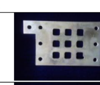
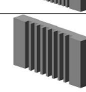
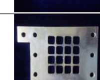
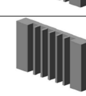
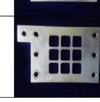


Figure 3. Planar and Ducted Cathode designs.

Table 1. Duct dimensions and Planar open areas studied

Ducted Design			Planar Design		
D1	2mm X 2mm		P1	44% open area	
D2	4mm X 4mm		P2	70% open area with uniform current collection	
D3	6mm X 6mm		P3	70% open area with non uniform current collection	

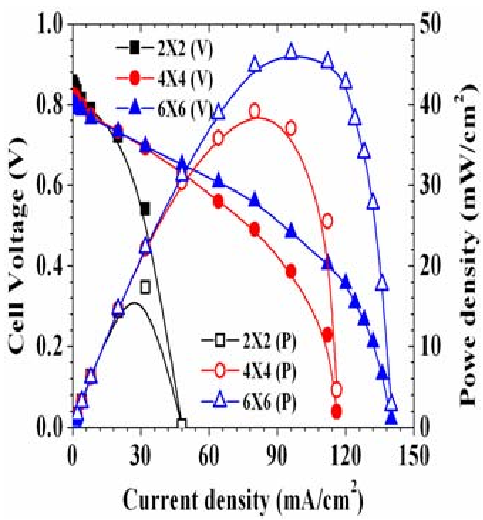


Figure 4. Hydrogen flow-DEM.

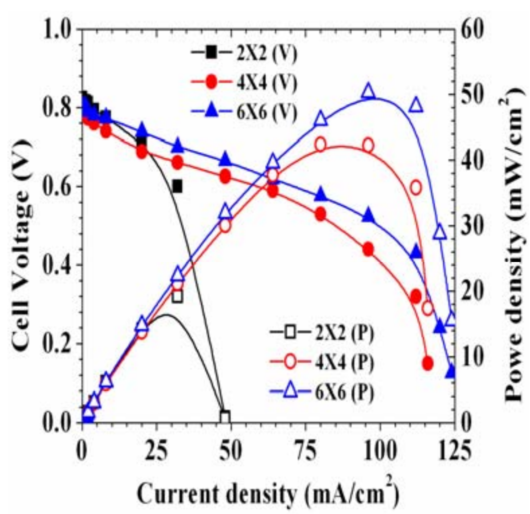


Figure 5. Hydrogen flow-0.1 LPM.

3.2 Effect of Planar Open Area

The different open areas studied for the planar design are shown in Table 1.[19] Experiments are conducted at the Dead End Mode (DEM), where the exit of hydrogen is closed and at 0.1 LPM and the observations are plotted as shown in Figure 6 and 7[20].

At Dead End Mode (DEM),it is observed that higher the open area of planar design, higher will be the performance. Even when the hydrogen is allowed to flow at 0.1 LPM, it is observed that performance is higher at higher open area of planar design[21].

It is observed from Figure 4 – 7 [that as the flow increases, the limited current density of an AB fuel cell increases due to increase in back diffusion[22].

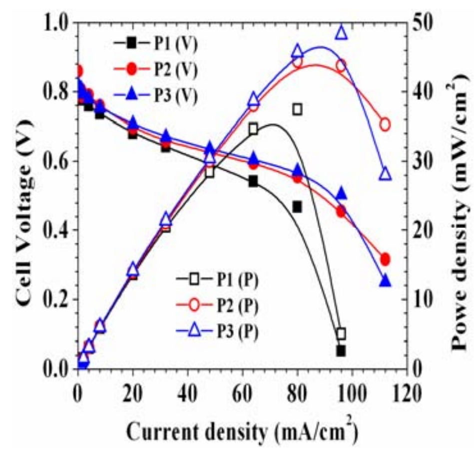


Figure 6. Hydrogen flow-DEM.

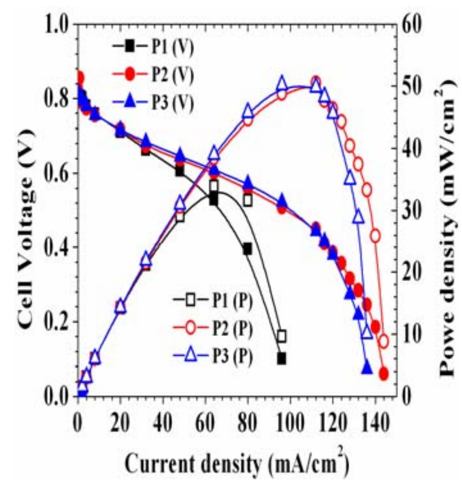


Figure 7. Hydrogen flow-0.1LPM.

3.3 Effect of Cell Orientation

3.3.1 Ducted Design

Experiments are conducted for ducted design (D3) at various cell orientations viz. vertical, horizontal with cathode upwards, horizontal with cathode downwards, 45° inclination with cathode upwards and 45° inclination with cathode facing down[23].

The observations at various cell orientations are plotted in Figure 8 and 9.

3.3.2 Planar Design

Experiments are conducted for planar design (P3) at various cell orientations viz. vertical, horizontal with cathode upwards, horizontal with cathode downwards, 45° inclination with cathode upwards and 45° inclination with cathode facing down[24].

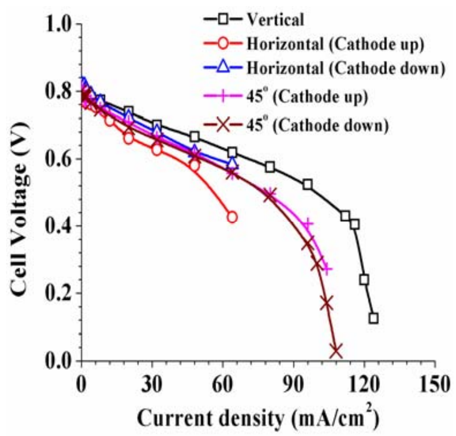


Figure 8. Voltage of an air breathing fuel cell at various cell orientations for ducted cathode design.

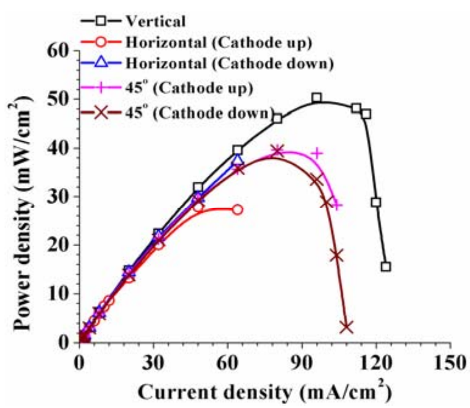


Figure 9. Power density of an air breathing fuel cell at various cell orientations for ducted cathode design.

The observations at various cell orientations are plotted in Figure 10 and 11[25].

It is observe from experimental results that vertical orientations is the best orientation for an air breathing fuel cell to operate because of higher performance for both ducted and planar designs[26]. The horizontal orientations are the worst orientations for an air breathing fuel cell to operate because of worst performance for both ducted and planar designs. Gravitational force affects the performance of fuel cell in horizontal orientation[27].

3.4 Effect of Ambient Temperature

3.4.1 Ducted Design

Experiments are conducted for ducted design (D3) at various ambient temperatures and the observations are in Figure 13 and 14[27].

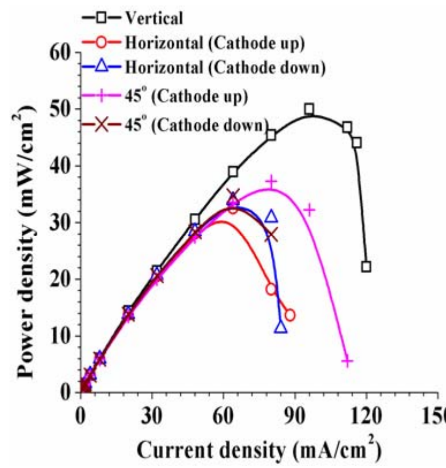


Figure 10. Voltage of an air breathing fuel cell at various cell orientations for planar cathode design.

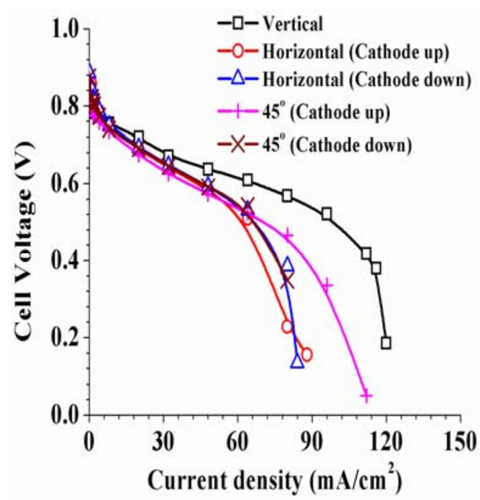


Figure 11. Power density of an air breathing fuel cell at various cell orientations for planar cathode design.

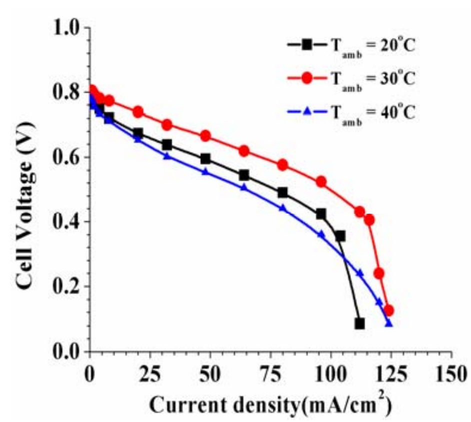


Figure 12. Voltage of an air breathing fuel cell at various ambient temperatures for ducted cathode design.

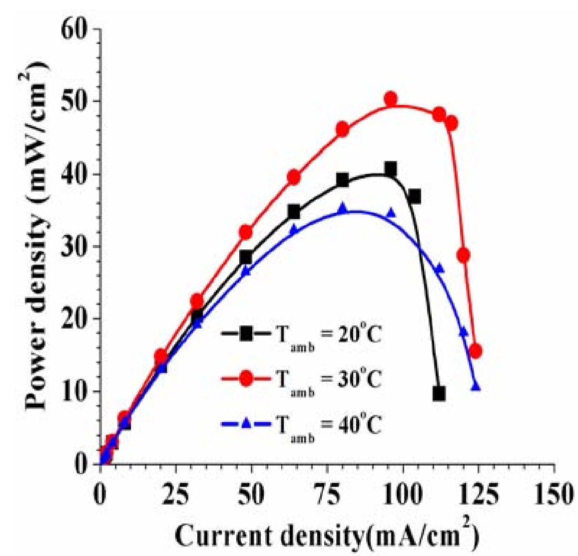


Figure 13. Power density of an air breathing fuel cell at various ambient temperatures for ducted cathode design.

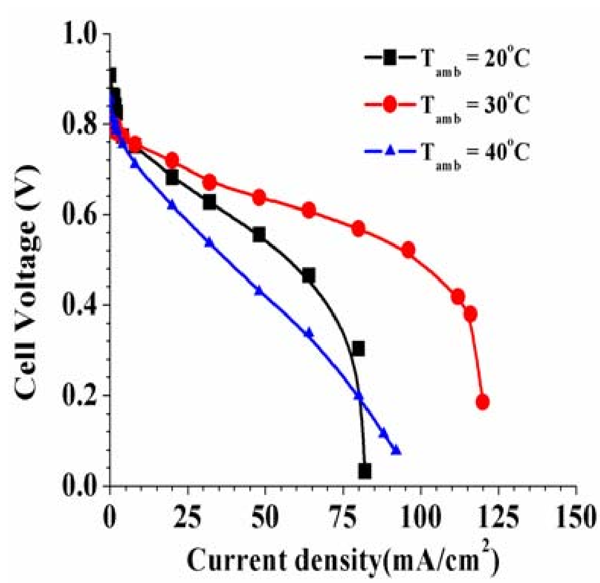


Figure 14. Voltage of an air breathing fuel cell at various ambient temperatures for planar cathode design.

3.4.2 Planar Design

Experiments are conducted for planar design (P3) at various ambient temperatures and the observations are in Figure 14 and 15[28].

It is observed form the experimental results that ambient temperature has a significant effect on the performance of an air breathing fuel cell. The performance is maximum at 30°C ambient temperature[29].

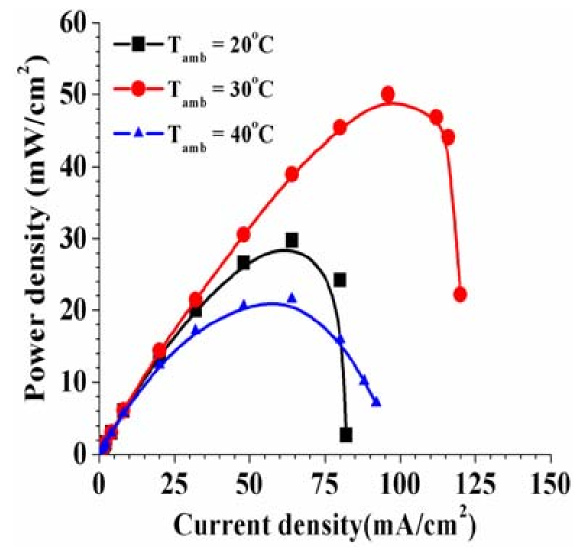


Figure 15. Power density of an air breathing fuel cell at various ambient temperatures for planar cathode design.

4. Conclusion

The experimental studies on air breathing fuel cell with ducted and planar design on cathode side were studied, including experiments with three different ratios of cathode open area with each design, varying the channel dimensions in the ducted design and varying the current collecting and the open area in the planar design. In ducted design the mass transfer limitations and flooding can be reduced with wider channels, where as in planar design larger opening area reduce the mass transfer limitations however wide channels require a rigid gas diffusion backing with current collecting ducts.

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The effect of varying hydrogen flow rate, various cell orientations, various ambient temperature, dynamic response and longtime operation of both ducted and planar designs were compared. The study of various cell orientation implied convective mass transfer limitation. The mass transfer limitations caused by liquid water saturation in long term measurements may not be critical in real small scale applications.

Following are the main conclusions drawn from this study.

- Higher the hydraulic diameter of the duct - better the performance.
- Higher the open area (planar cell) - maximum performance.
- Increase in hydrogen flow rate - Increases back diffusion; Increases limiting current density.
- Vertical orientation gives best performance - higher heat and mass transfer coefficients.
- Horizontal orientation - worst performance - has a significant increase in mass diffusion over potential - affected by the gravitational force.
- Ambient temperature has a significant effect on air-breathing fuel cell performance.

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