Performance of gas diffusion layer from coconut waste for proton exchange membrane fuel cell

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Abstract. The performance of Gas Diffusion Layer (GDL) synthesized from coconut waste. Gas Diffusion Layer (GDL), produced from coconut waste, as a part of Proton Exchange Membrane Fuel Cell (PEMFC) component, has been characterized. In order to know the performance, the commercial products were used as the remaining parts of PEMFC. The proposed GDL possesses 69% porosity for diffusion of Hydrogen fuel and Oxygen, as well as for transporting electron. With the electrical conductivity of 500 mS.cm$^{-1}$, it also has hydrophobic properties, which is important to avoid the reaction with water, with the contact angle of 139$^\circ$. The 5 x 5 cm$^2$ GDL paper was co-assembled with the catalyst, Nafion membrane, bipolar plate, current collector, end plate to obtain single Stack PEMFC. The performance was examined by flowing fuel and gas with the flow rate of 500 and 1000 ml.min$^{-1}$, respectively, and analyse the I-V polarization curve. The measurements were carried out at 30, 35, and 40$^\circ$C for 5 cycles to ensure the repeatability. The results shows that the current density and the maximum power density reaches 203 mA.cm$^{-2}$ and 143 mW.cm$^{-2}$, respectively, with a given voltage 0.6 V, at 40$^\circ$C.

1. Introduction
Proton Exchange Membrane Fuel Cell (PEMFC) is a device which converts hydrogen fuel into electrical energy via electrochemical process [1-4]. PEMFC consists of components, i.e. Nafion membrane, catalyst, Gas Diffusion Layer (GDL), bipolar plate, and end plate [1,3], which are assembled to become a stack. As a main part of PEMFC, GDL plays the essential role for transporting gas from the supply channel to the electrode. In PEM fuel cells, the GDL must also permit water to be transported from the electrode into the gas flow channels where it is moved out from fuel cell. The gas diffusion layer is a porous membrane that must permit transport of reactant gases to the electrode and provides a path for the product water to be removed from the catalyst layer [5,6]. The typical support material for GDL is carbon-based materials, such as carbon fiber [7], carbon nano-tube (CNT) [8], and carbon black [9]. These carbons can be synthesized from biomass waste, such as coconut waste, by manipulating the properties. Coconut waste is one type of natural resource, which contains complex organic compounds, i.e. hemicellulose, cellulose and lignin [10]. These complex organic compounds decompose at different temperature ranging from 200$^\circ$C to 500$^\circ$C [10], and produce charcoal with high carbon content [11]. In the present study, coconut waste was used as a precursor to make carbon paper for gas diffusion layer in PEMFC. If it can be utilized as a material for GDLs, the sustainability issues can also be resolved. The objective of this work is to investigate the performance of carbon paper made from coconut waste, which serves as gas diffusion layer in fuel cell stack.
2. **Material and method**

1.1. **Material**

Coconut waste was used as a carbon precursors. Ethylene vinyl acetate (EVA) and Polyethylene glycol (PEG) obtained from Aldrich Chemical Co., Inc. (St. Lois, MO, USA) was used as a binder. Xylene as a solvent was obtained from Brataco Chemika. Teflon emulsion PTFE 30, obtained from Fuel Cell Earth LLC, was used as a hydrophobic agent of the carbon paper. Teflon emulsion PTFE 30 should be diluted to a concentration of 20% before it is coated on the surface of the carbon paper.

1.2. **Preparation of carbon materials**

The carbon materials were prepared from coconut waste and were used in two forms, i.e. carbon fiber and carbon powder. Both carbon materials were prepared by a two stage process: carbonization at 500°C and pyrolysis at 900°C, which is followed at 1300°C under N₂ atmosphere. The carbonization process produced charcoal with high carbon content. While, the pyrolysis process produced carbon materials with better physical properties, especially for the electrical conductivity. To produce the carbon fiber, coconut waste was cut into 2 mm size, before experience the carbonization and pyrolysis processes. While, the carbon powder was obtained by grinding the carbon material into a powder of about 74 µm size.

1.3. **Preparation of carbon paper**

Carbon paper was prepared by mixing the carbon material (carbon fiber:carbon powder = 7:1) with polymer EVA and PEG in xylene at 100°C for 2 hours to make slurry, which then casted on glass mold with dimension of 10 cm x 10 cm. The carbon paper sheet was dried at room temperature for 24 h. To enhance the hydrophobic property of carbon paper, it was immersed in 20 % PTFE suspension for 30 minutes and dried at room temperature overnight. Then, it was heated at 150°C for 30 minutes, followed by heating at 350°C for 30 minutes.

1.4. **Characterization of carbon paper**

Through-plane electrical conductivity of carbon paper was measured using HIOKI 3522-50 HITESTER LCR-meter. Porosity was determined by the kerosene density method using Archimedes principle in accordance with BS 1902: Part 1A standard. Hydrophobic properties were determined by the contact angle measurement using sessile drop test. For the contact angle measurement, a 50 µL water droplet was placed on the carbon paper surfaces. The tip of syringe position was directed close enough to the sample surface, while the images were captured. Furthermore, the droplet shape was analyzed using Bashforth and Adams tables [13] to determine the contact angle of the samples.

1.5. **Single PEMFC operation measurement**

Each PEM fuel cell components have to be assembled into one stack. The first step is the attachment of GDL paste electrode with membrane, where the heat treatment at 100°C for 2 minutes with the applied force of about 2kgf is needed. The Membrane Electrode Assembly (MEA) was then moved to make sandwich-like sample with the rest of components, from the outside end-plate to gasket, bipolar plate, another gasket, then MEA, gasket, bipolar plate, gasket, and closed with end-plate. This stack was locked with rod at every edge by means torque of 2N.m.
3. Result and discussion

Polarization tests were carried out at 30, 35, and 40 °C, with the hydrogen fuel and gas oxygen flow rate of 500 and 1000 ml.min$^{-1}$, respectively. In the beginning, the measurement was carried out at 30 °C for five cycles in order to know the consistency of the polarization curves for this GDL. Figure 1 shows the polarization curve at 30 °C, where the obtained current density is 200 mA.cm$^{-2}$ in ohmic region for 0.6 volt. While, the maximum power density is 145 mW.cm$^{-2}$ at 30°C. When the temperature is raised to 35 °C and 40 °C, the current density in ohmic region become 189 and 196 mA.cm$^{-2}$ as presented in figures 2 and 3, respectively. In fact, the fluctuation of current density at various temperatures is not significant since the cell was operated at low temperature. The maximum power densities are 141 and 143 mW.cm$^{-2}$, which was obtained at 35 and 40°C, respectively.

![Figure 1.](image1.png)

**Figure 1.** Polarization curve of PEM fuel cells with GDL from coconut waste at 30 °C.

![Figure 2.](image2.png)

**Figure 2.** Polarization curve of PEM fuel cells with GDL from coconut waste for temperature 35°C.
Figure 3. Polarization curve of PEM fuel cells with GDL from coconut waste for temperature 40°C.

Since we repeated the measurement for five times in five cycles, the average of the maximum density should be considered. The graph of power density versus temperature in figure 4 shows that the deviation of characteristic carbon as GDL at 30, 35, and 40 °C are 2, 1, and 2%, respectively. It can be seen that the carbon made from coconut waste is a promising material for Gas Diffusion Layer. The polarization curve looks relatively stable. The electrical conductivity could reach up to 500 mS.cm\(^{-1}\), with porosity of about 69%. In addition, this material possesses good hydrophobic properties, which is shown by the contact angle of 139°.

Figure 4. Power density of PEM fuel cells with GDL from coconut waste at different temperature

4. Conclusion
In this work, the carbon paper from coconut waste was synthesized, and its performance as a gas diffusion layer in fuel cell stack was examined. The characteristic is shown in polarization curve at
various temperatures. The achieved power density is statistically stable with the deviation of 1-2%. In other word, the carbon from coconut waste is promising material for GDL of fuel cell.

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