CHAPTER 7

CONCLUSIONS

This dissertation studies the analysis of electron transfer in the bio-fuel cell (BFC). Chapter 1 and 2 give a brief outline of fuel cell, BFC, basic background and knowledge necessary to understand the behavior of the BFC. Chapter 3 describes materials and methods used in the experiments. Chapter 4 shows the effect of electrode materials on the BFC performances and the impedance analysis. The geometric parameters have been investigated in chapter 5. The studies of biological and chemical concentrations, electron mediators and electron acceptors are described in chapter 6. The following results can be summarized from the investigations.

7.1 Impedance Analysis of BFC

Electrical impedance model was used to describe the characteristics of the BFC. The total impedance includes electrode impedance, electrode-solution interfacial impedance, solution impedance and PEM impedance. It was found that the electrode-solution interfacial plays the most important role in power transferring to load. The lower the electrode and solution impedances will lead to the higher power transfer to load.

7.2 Physical Parameters

Electrode material, surface area, distance between electrodes and compartment volume are physical parameters that have been investigated.

1. Electrode material

It was found that carbon fiber is the most suitable material for using as the BFC electrode because carbon fiber is a non-toxic, physically and chemically stable, and inexpensive material. Moreover, it was found to have a relatively low interfacial impedance. Even the carbon fiber has a little bit higher electrode-solution interfacial impedance than silver, but it is more stable and less toxic. The interfacial impedance of the carbon fiber electrode in PB was 4.96kΩ. Hence, the carbon fiber electrode could supply current up to 31mA/m^2 that was higher than nickel, stainless steel and aluminum electrodes even though the carbon fiber electrode could generate open-circuit voltage only ~330mV that was lower than the nickel and stainless steel electrodes. The voltage-current density characteristics of different electrode materials are presented in Fig. 7.1.

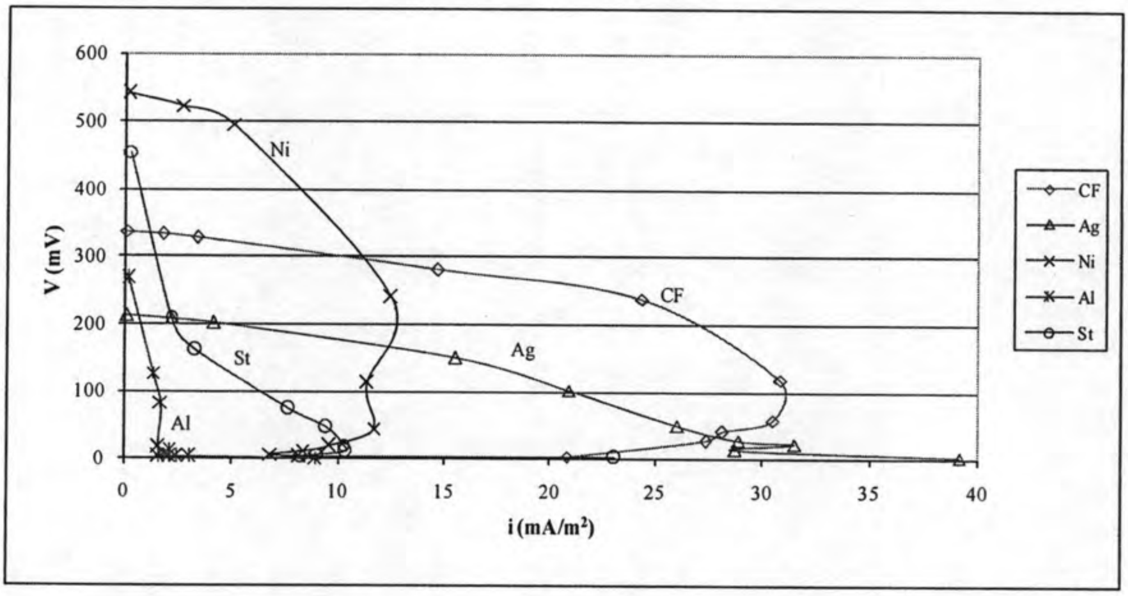

Fig. 7.1 Voltage vs. current density of the BFC when using different electrodes

2. Electrode surface area

Since the solution, electrode and electrode-solution interfacial impedances are inverse proportion to the electrode surface area, then increasing the electrode surface area will reduce the impedance. It was observed that the impedance of the system decreases to ~2kΩ when using electrode having area of 50cm^2. However it was found that power of the BFC increases as surface area increased while the highest power density was obtained from the BFC having surface area of 18cm^2. The power-load and power density-load characteristics of the BFC are shown in Fig. 7.2 and Fig. 7.3, respectively.

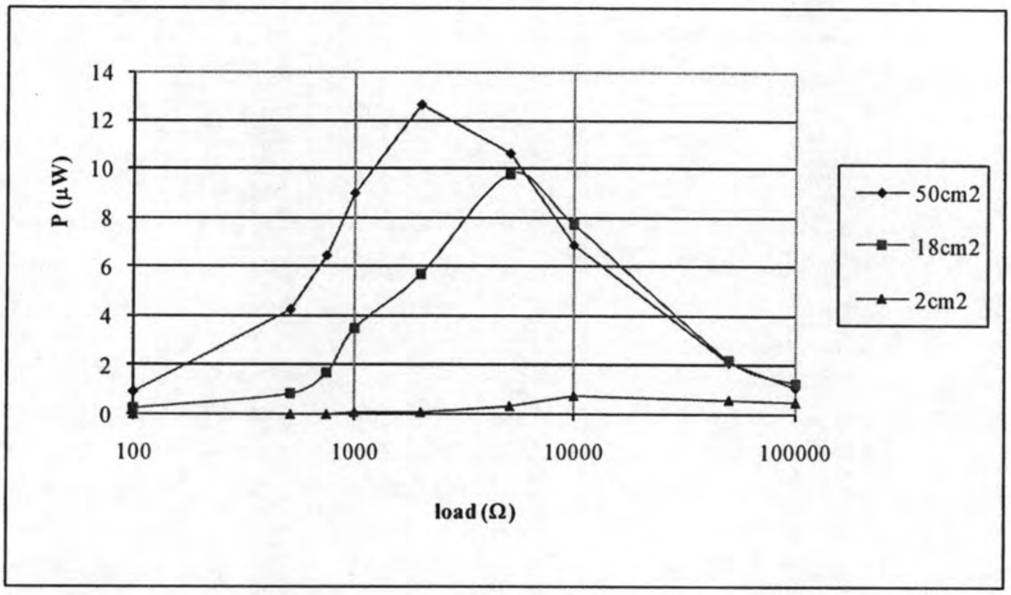

Fig. 7.2 Power-load characteristics of the BFC with different electrode surface areas

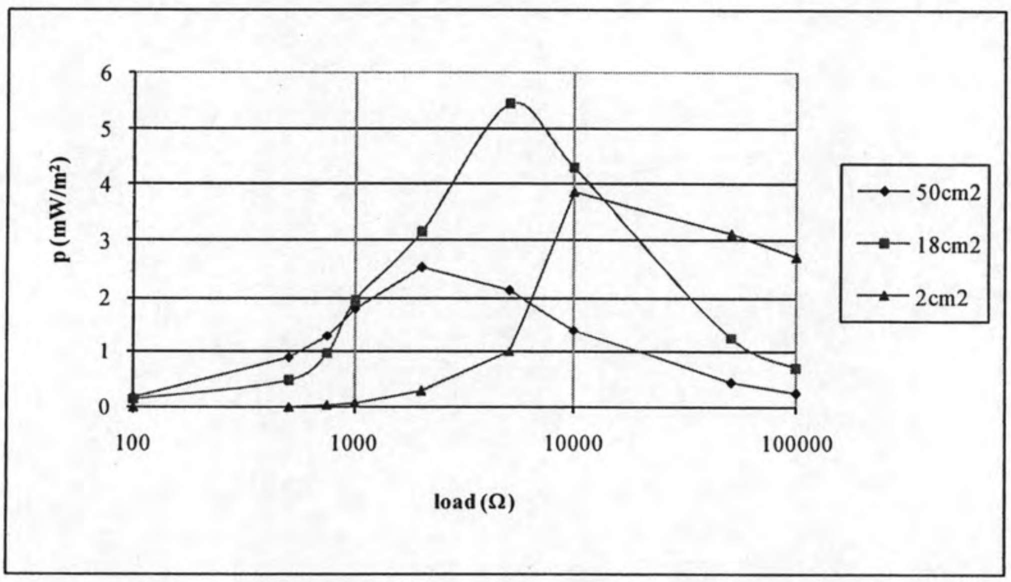

Fig. 7.3 Power density-load characteristics of the BFC with different electrode surface areas

3. Distance between electrodes

As the impedance of solution varies with the gap between the two electrodes, then it was assumed that the impedance of the system will increase as the gap is increased. However, this was not observed for the gap in the range of 2~20cm. as shown in Fig 7.4. because the solution impedance of these conditions was lower than 93Ω, which is much smaller than the electrode-solution interfacial impedance (~1kΩ).

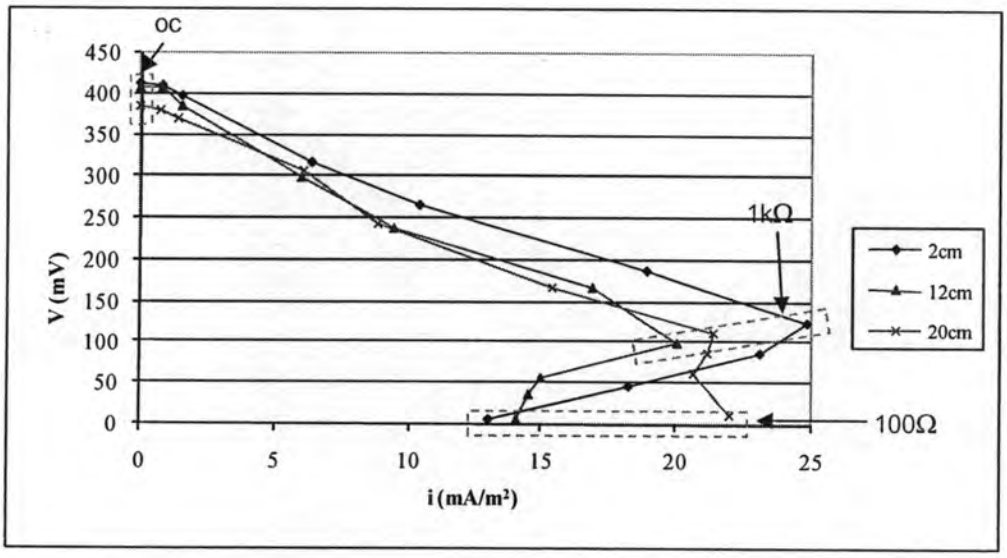

Fig. 7.4 Voltage vs. current density of the BFC with different distances between electrodes

4. Compartment volumes

Increasing volume at fixed concentration of the components in the BFC will increase number of molecules for the reaction which will lead to increasing of electron in the system. As found in Fig.7.5, the total charge obtained from the BFC increases as volume is increased up to 210ml. However, the total charge decreased at volume higher than 210ml. Since the experiments were operated under un-stirring condition, the electron generated from the cell far from the electrode will take more time and/or more loss before reaching to electrode. This might be the reason why the total charge decreased at volume higher than 210ml.

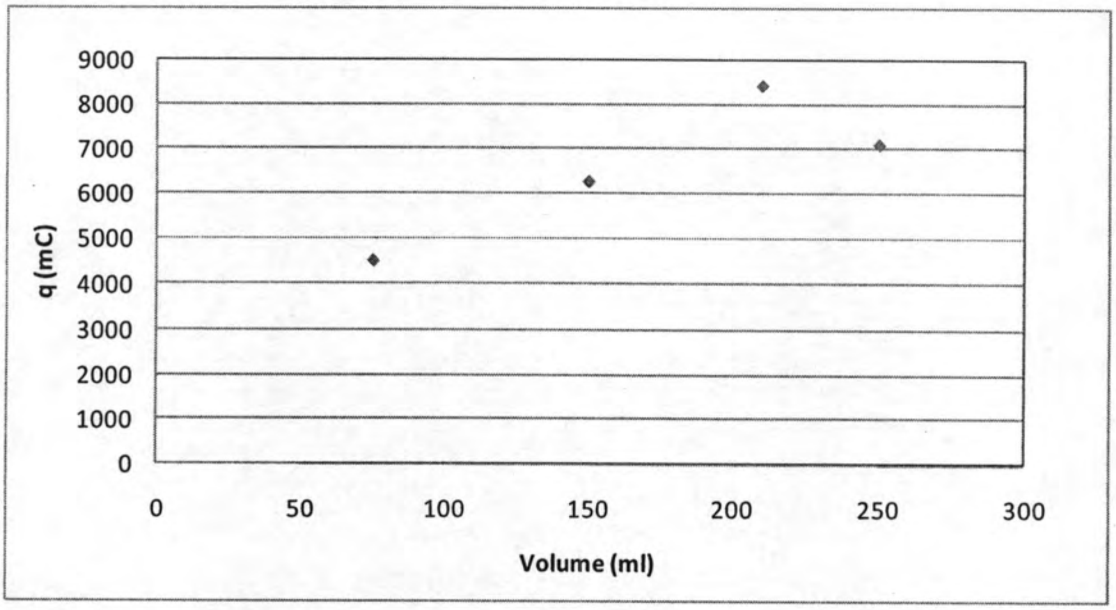

Fig. 7.5 Relationship between the total charge and volume at fixed component concentrations

7.3. Chemical Parameters

Chemical components, i.e. glucose, electron mediators and electron acceptors, have been investigated to find an optimal condition for the BFC construction.

1. Glucose

The results show that the increasing of the glucose concentration will decrease the Thevenin resistance and increase the current and power generation of the BFC. The voltage-current density of the BFC is displayed in Fig. 7.6. Since the glucose will be consumed during the electrical generation, fed-batch should be performed for construction of the BFC.

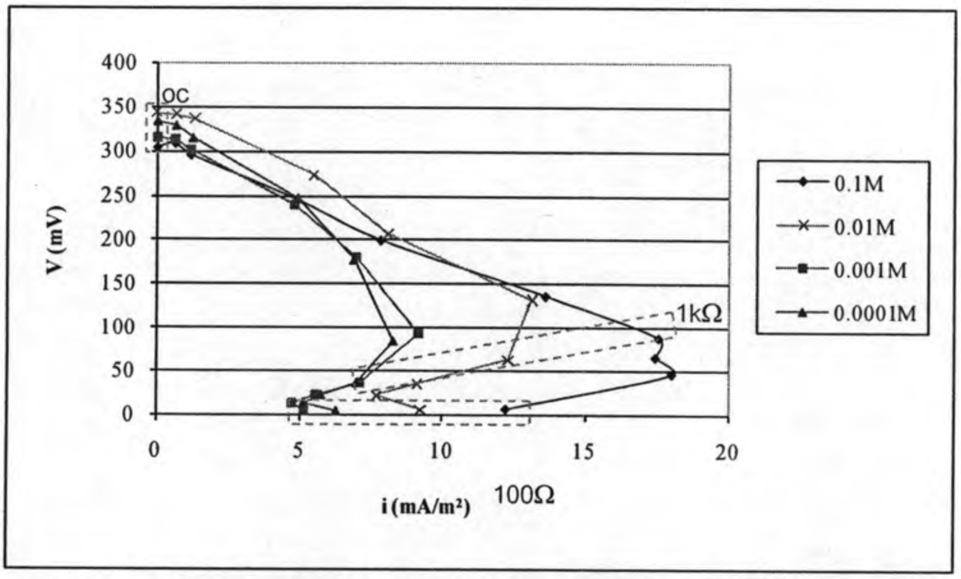

Fig. 7.6 Voltage vs. current density of the BFC with different glucose concentrations

2. Electron mediators

The best electron mediator should be a good electron acceptor for receiving electron from microorganism while it should be a good electron donor in transferring electron to electrode. It was found that the methylene blue accepted the electron from the cell better than neutral red and rhodamine B because methylene blue has the higher reduction half-cell potential. Hence, the methylene blue has more electrons for supplying to electrode than neutral red and rhodamine B. The BFC result with different electron mediator is shown in Fig. 7.7.

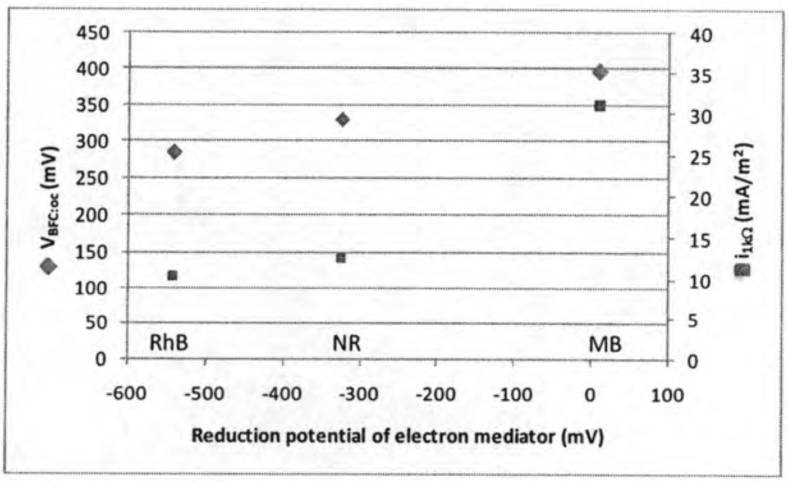

Fig. 7.7 Open circuit voltage and current density at 1kΩ load of the BFC vs. reduction potential of each electron mediator

The current can be enhanced by increasing the methylene blue concentration. No relation between the methylene blue concentration and the Thevenin resistance or power generation. Fig. 7.8 shows the voltage-current density with different methylene blue concentrations. This implies that increasing the electron mediator will increase the electron transfer in the BFC.

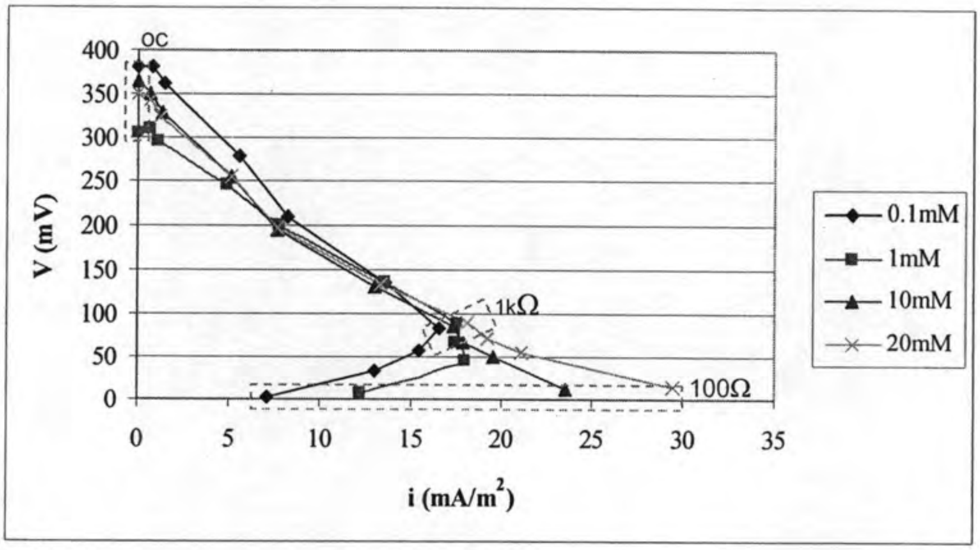

Fig. 7.8 Voltage-current density of the BFC with different methylene blue concentrations

3. Electron acceptors

It was found that ferricyanide was the better electron acceptor than oxygen although the half-cell reduction potential of the oxygen is higher than ferricyanide. This might be due to the very low dissolved oxygen (8 ppm) in the solution. The increasing of ferricyanide can decrease Thevenin resistance and increase voltage, current and power generation of the BFC. Fig. 7.9 presents the voltage-current generation of the BFC when using different ferricyanide concentration. However, the combination usage of ferricyanide and oxygen offers the best condition for generating voltage (0.45V), current density (83 mA/m^2) and power density (9 mW/m^2). At this condition, the lowest Thevenin resistance of 797 Ω was achieved. The voltage-current characteristics of BFC with different electron acceptors are shown in Fig. 7.10. The results indicate that the higher electron acceptor, the higher performance could be achieved. However, the ferricyanide is toxic hence it should be aware.

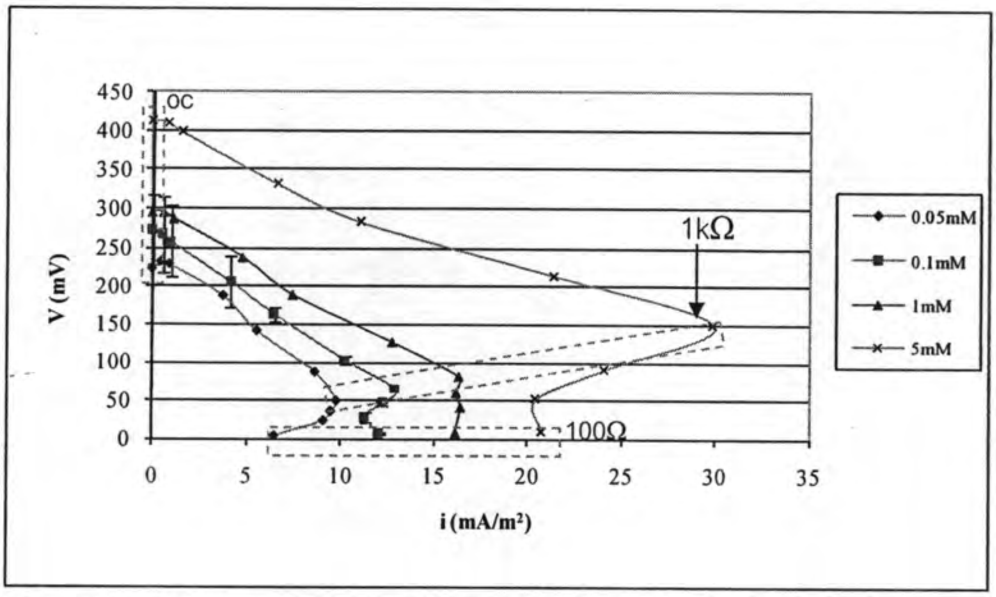

Fig. 7.9 Voltage-current characteristics of the BFC with different ferricyanide concentrations

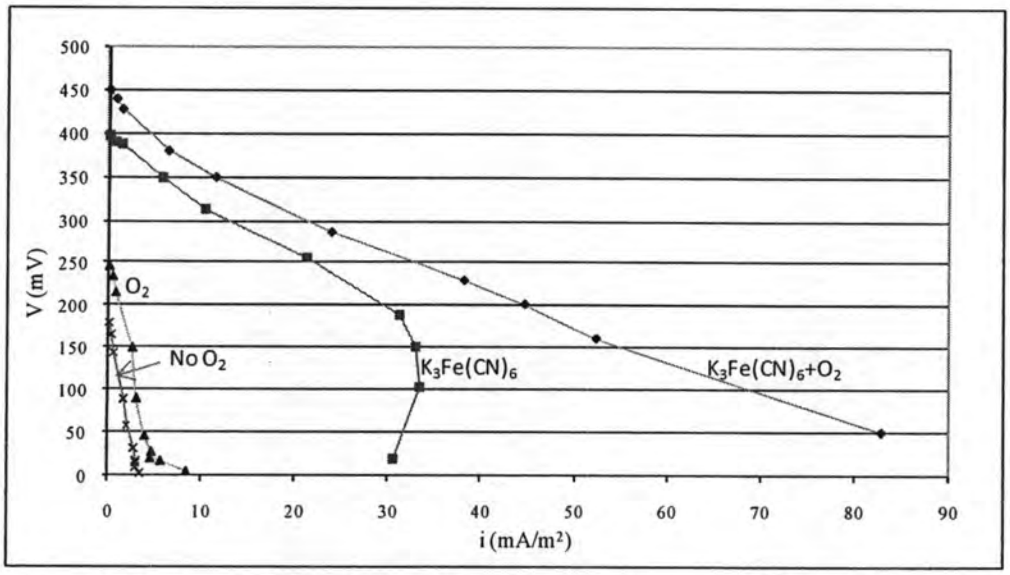

Fig. 7.10 Voltage – current characteristics of the BFC with different electron acceptors

7.4 Biological parameters

It was found that the Thevenin resistance will decrease and the voltage, current and power generation will increase if the concentration of yeast is increased. This implies that higher concentration of microorganism is preferred for construction of the

BFC. The voltage-current density with different yeast concentration is displayed in Fig. 7.11.

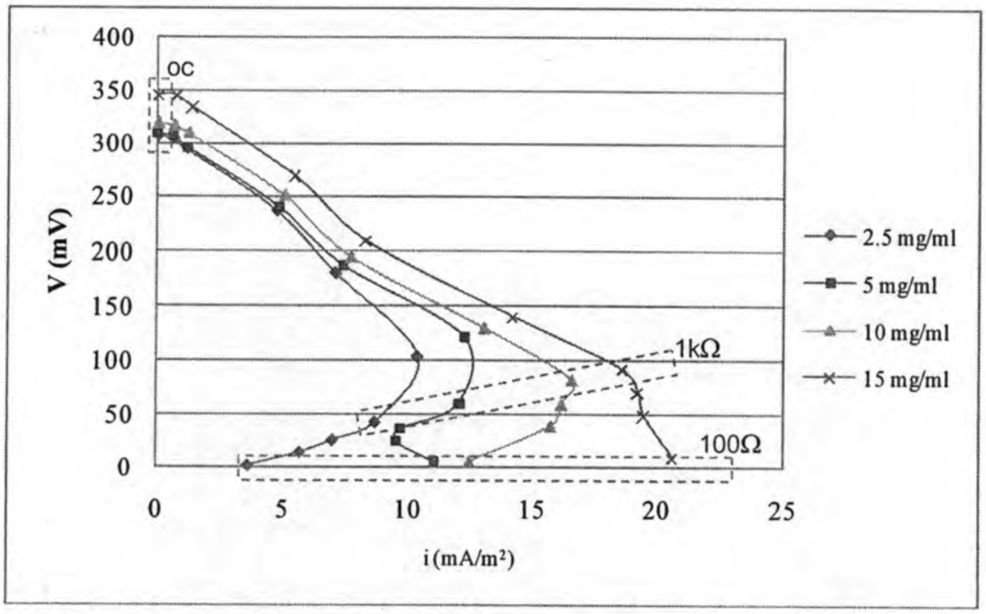

Fig. 7.11 Voltage-current density of the BFC with different yeast concentrations

7.5 Summary

The present dissertation has been attempted to investigate the contribution of each component in the BFC on its characteristics, and then elucidate it in the form of electrical equivalent circuit. It could be concluded that to enhance the BFC performances, the system should be designed to have low Thevenin resistance. This is feasible by using carbon fiber together with high concentration of fuel (glucose), microorganism (yeast) and electron acceptor (ferricyanide). The role of electron mediator (methylene blue) concentration on the Thevenin resistance was not observed in the range of 0.1~20mM. Moreover, It was also found that the combination usage of electron acceptors; ferricyanide together with oxygen, could enhance the BFC performance. The highest open circuit of ~ 0.45 mV, current density of ~83 mA/m^2 and power density of ~9 mW/m^2 was obtained from the BFC with the following conditions,

Electrode : carbon fiber (area: $50cm^2$)

Fuel : Glucose 53mM

Microorganism : Yeast 21mg/ml

Electron mediator : MB 3mM

Electron acceptor : Ferricyanide 0.5mM + oxygen 500ml/min

PEM : Neosepta® (size: 5x5 cm^2)

7.6 Suggestions

1. This work has been carried out in batch operation. It is suggested that the fed-batch operation should be performed for a continuous power generation.

2. A portable BFC might be developed by using mediator-less microorganism and using oxygen from air as electron acceptor.

3. Waste water is an interesting fuel for development of the BFC that could generate power while treat the waste.