Direct Methanol Fuel Cells for Telecommunications

H Joubert, MJ Case* and HCvZ Pienaar*

Abstract—The demand for higher efficiency and cleaner power sources increases daily. The Direct Methanol Fuel Fells is one of those power sources that produce reliable electrical energy at high efficiencies and very low pollution levels. Remote telecommunication sites need power sources that can deliver reliable power. This paper describes some important design aspects of DMFC's as well as results obtained.

Index Terms—Direct Methanol Fuel Cell (DMFC); Methanol crossover; Ohmic resistance; Nafion membrane; Membrane Electrode Assembly (MEA).

I. INTRODUCTION

Generating environment friendly electrical power is something more people and companies should be concerned with. Although the Telecommunication Industry is a small consumer of electric power, it must remain aware of the problem of pollution easily generated by fossil fuel plants. The direct methanol fuel cell generates electrical power very efficiently and with very low emission levels.

Sir William Grove developed the fuel cell in 1839. A fuel cell is an electrochemical device that converts the chemical energy of a fuel, such as a methanol solution, and an oxidant, such as air, into electrical energy with the help of a catalyst. DMFC's are very similar to batteries. DMFC's consist of the same basic components as a battery. They have an anode, cathode and an electrolyte. The oxidation of the fuel occurs at the anode according to the following reaction:

$$CH_3 + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$$

The reduction of the oxidant at the cathode is represented by the following reaction.

$$\tfrac{2}{3}O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$$

The overall reaction in the direct methanol fuel cell is thus:

$$CH_3OH + \tfrac{2}{3}O_2 \rightarrow CO_2 + 2H_2O$$

DMFCs will continuously produce electricity as long as the fuel and the oxidant are supplied to it. A single direct methanol fuel cell can only supply 0,3 to 0,5 V under load conditions. Therefore, a number of cells need to be connected in series in order to obtain a higher voltage level. The cells in series are referred to as a direct methanol fuel cell stack. The current from the cell is obtained from the size of the active catalytic area, measured in mm^2.

The DMFC could supply any system that requires electrical power to operate with the required power. They are also modular and therefore, could easily be installed at a required site. The site can be remote or in a suburban area. Some telecommunication sites are remotely situated. For these sites the DMFC could be used as a primary source of power. Telecommunication sites that are in suburban areas with a power grid available can use the DMFC as a secondary or backup power source.

II. MANUFACTURING OF DMFC STACK

A. *The membrane electrode assembly*

The hart of any fuel cell is the membrane electrode assembly (MEA). The MEA consists out of a proton conducting membrane, an anode electrode catalyst and a cathode electrode catalyst all diffused together. Figure 1 shows an example of the MEA used in the DMFC.

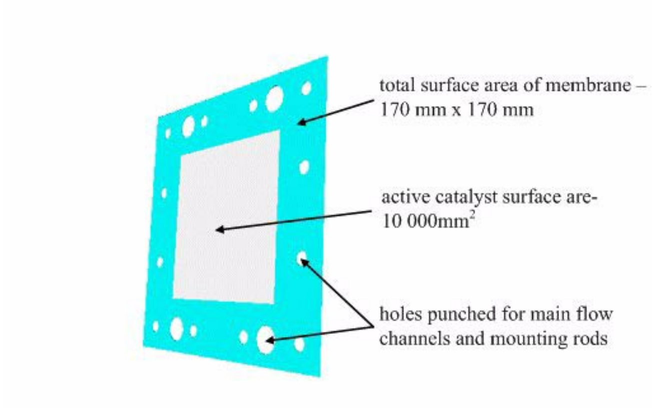

Figure 1 Example of an MEA.

B. *The gas diffusion layer*

Gas diffusion layers are placed of either side of the MEA. The function of the gas diffusion layers is to facilitate the reactant flow to the catalytic active site. GDL's can be

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hydrophobic or hydrophilic. A gas diffusion layer at the anode must be hydrophilic. This would help in the mass transport of the liquid fuel to the anode catalyst.

The gas diffusion layer at the cathode must be hydrophobic in order to repel the water that forms at the cathode during fuel cell operation. A GDL normally consist out of porous carbon paper. An example of a gas diffusion layer is shown in figure 2.

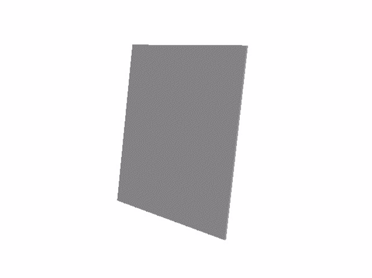

Figure 2 Gas diffusion layer.

C. Design of flow field plates

The function of the flow field plates is to ensure that the fuel and oxidant comes in contact with the anode catalyst and cathode catalyst of the MEA respectively. Also including the fact that the reactant fuel and oxidant doesn't leak out of the specific cell. In other words the flow field plates form a of chamber around the active electrode catalyst on either side of the MEA. Figure 3 illustrates the flow field plates than were designed.

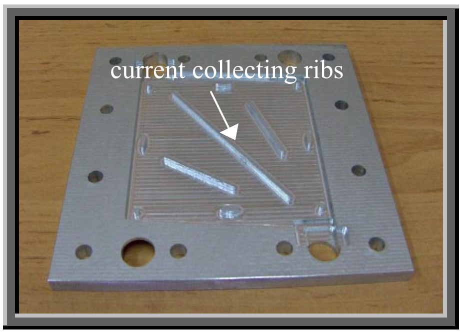

Figure 3 Direct methanol flow field plate.

The direct methanol fuel cell uses a methanol-water solution as fuel. The methanol solution is in a liquid form. Therefore, the flow field plate must enable the liquid fuel to be circulated over the complete active surface area of the anode catalyst. Another important fact to keep in mind is that the liquid must flow from the bottom of the anode chamber to the top. This will make sure that the liquid methanol-water solution will come in contact with the complete anode catalytic surface area as the liquid will displace the air or air pockets.

The ribs in the chamber area are used to support the gas diffusion layers and the membrane. It also collects the current from the GDLs and the membrane. See figure 4.

On the other side of the flow field plate the air is circulated in the cathode chamber and this forms part of the next cell. As is illustrated in figure 5.

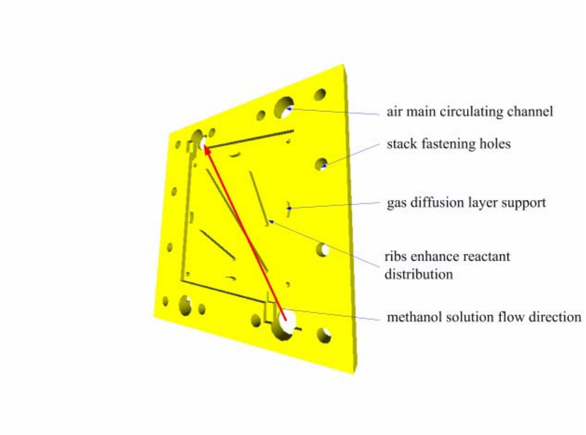

Figure 4 Liquid flow direction in the DMFC.

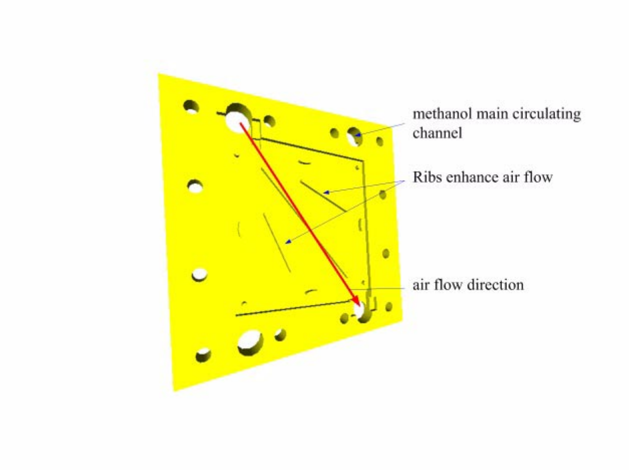

Figure 5 Air flow direction in the DMFC.

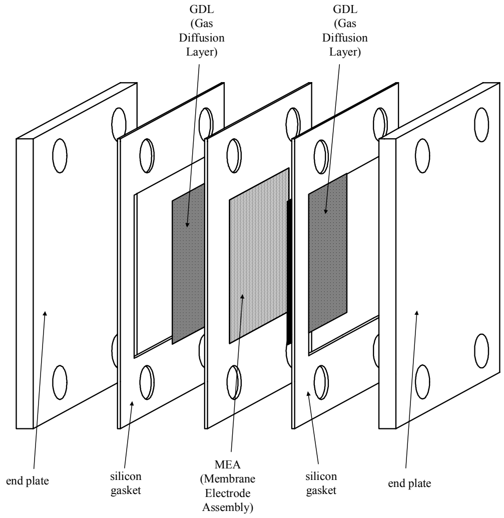

Figure 6 DMFC stack concept.

D. DMFC stack

Two of these flow field plates are required in order to make up one direct methanol fuel cell. Figure 6 illustrated the concept of the DMFC stack. In this representation there are two cell stacked in series. It also includes the gas diffusion layers and the silicon casketing that ensures that no air or liquid leaks occurs. The stack is then closed up so to speak with end plates.

The completely manufactured DMFC stack is shown in figure 7. The DMFC stack consisted out of five cells in series. The white polypropylene end plates are clearly visible with the needed plumbing attached to it. The silicon gaskets are also clearly visible between the flow field plates. The stack are tightly bolted together to avoid any fuel from leaking out.

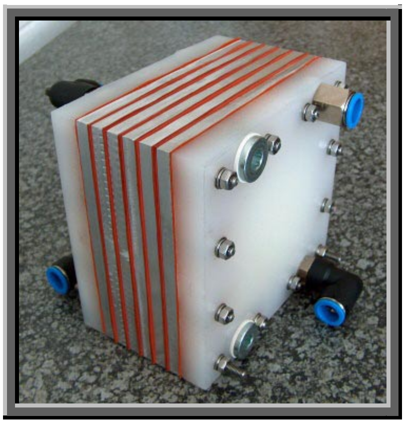

Figure 7 Assembled DMFC stack.

III. BUILDING AND SETUP OF DMFC TEST RIG

The mechanical structure of the test rig consists out of a frame with a platform onto which all the various pumps, tanks and a blower are mounted. Figure 8 gives a block diagram of the test rig. It is important to make sure that the materials used to store, block, mix or guide methanol or the methanol solution must be chemically resistant towards this liquid and its mixtures.

It is also recommended that the blower and all pumps must be able to operate on 12 volts. Careful attention must be given not to choose a device that is overrated for the function that it must perform. This will only use more power from the DMFC than necessary. The devices must also be able to operate on lower voltages than 12 volt. The reason for this is to control air and fuel flow rates.

Figure 9 shows a photo of the complete direct methanol fuel cell test rig. All of the components that are used to run the stack are easily accessible. Two external variable 12 volt power supply was used to power both the air blower and the liquid methanol solution pump respectively.

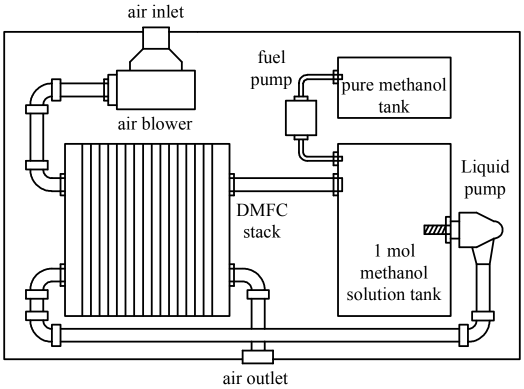

Figure 8 Block diagram of test rig.

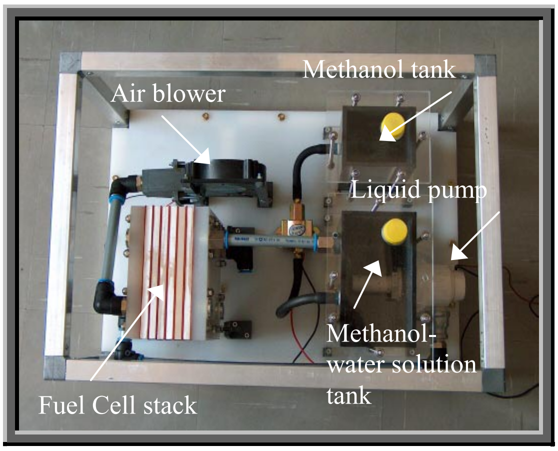

Figure 9 Direct methanol fuel cell test rig.

IV. PERFORMANCE OF A DIRECT METHANOL FUEL CELL

A. *Startup of the stack*

Before the fuel cell could be used for the first time a few important steps should be followed. There are two different startup scenarios. The first is the initial first run of the stack. In other words, the stack is being operated for the first time after it has been assembled, the MEAs' have not been used in a fuel cell before. The second is when the stack has been power down and after a while powered up again. The fuel cell is now "matured".

Figure 10 shows the response of the fuel cell where the FC stack was operational for the first time.

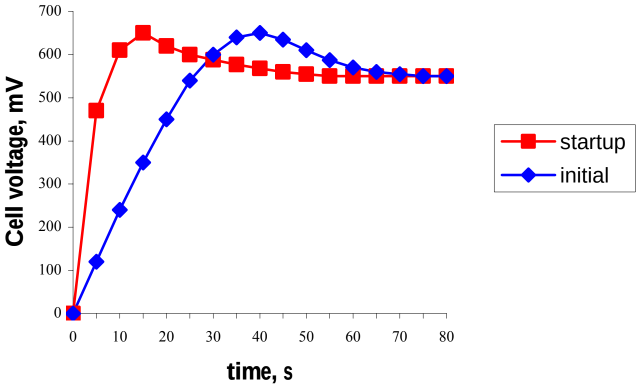

Figure 10 Initial startup of a DMFC stack.

Figure 10 also shows the startup of a matured stack. It is clear from both of these figures that the open circuit voltage (OCV) reaches a maximum value and then stabilizes at a lower value thereafter.

B. *Voltage-Current density*

The voltage-current density characteristic curve of the direct methanol fuel cell is given in figure 12. According to Shen et al. [3], there are three distinct regions in a fuel cell performance curve.

This is given by regions A, B and C in figure 11. In region A the cell currents are low and the cell voltage is dependent on the electrochemical kinetics of the anodic methanol diffusion. In region B the current load increases.

This causes the cell voltage to decrease further due to internal resistance of the fuel cell. This region is also called the Ohmic controlled current density region. In region C the fuel cell reaches a limiting current density condition. At this point the cell voltage breaks down. The limiting current density depends on the mass transport resistance of methanol in the anode diffusion layer.

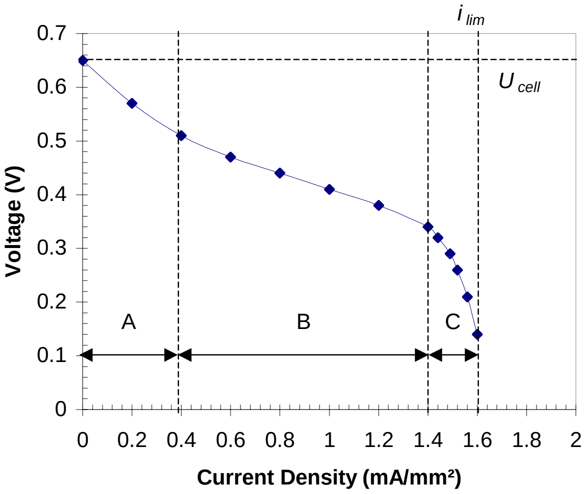

Figure 11 Voltage-current curve of a DMFC.

Sundmacher et al. [5] explains that the performance curve of a fuel cell is also influenced by the formation of CO_2 bubbles on the anode surface. This depends on the operating conditions of the cell.

The open circuit voltage of a Direct Methanol Fuel Cell (DMFC) is in the range of Ucell = 0.6 – 0.7 V (see figure 12). Sundmacher et al. [5] says that this is much lower than the thermodynamically expected value of 1.2 V. The reason for this lower voltage is due to the formation of mixed potentials because of undesired side reactions at both electrodes. The theoretical open circuit voltage of the direct methanol fuel cell can be calculated by the following formula [1]:

$$E = \frac{-\Delta\left(\overline{gf}\right)}{zF}$$

where $E \equiv$ Voltage of direct methanol fuel cell, V.

$\overline{gf} \equiv$ Gibbs free energy of elements in their molar form, $\mathrm{KJmol^{-1}}$.

$z \equiv$ Number of electrons transferred in the external circuit.

$F \equiv$ Faraday's constant, 96485 C.

$$E = \frac{-(-698.2)}{6 \times 96485}\ \mathrm{KJmol^{-1}C^{-1}}$$

$$E = 1.21\ \mathrm{V}$$

Another factor that plays a big role in the lower cell voltage is methanol crossover. Methanol permeates through the membrane from the anode to be oxidized at the cathode.

C. *Power-current density.*

In figure 12 a power response curve is given. This curve is derived from the voltage-current density data obtained in figure 11. The plots are made by using the formula P = V times I. Surprisingly, maximum power is available at a current density of 1,40 mA/mm². Referring back to figure 11, this is at the end of region B. The cell voltage is already low at this point, in the order of 350 mV. Therefore, operating the fuel cell stack at a higher cell voltage will not ensure maximum power density. This will have the result of more cells required in the stack to maintain maximum power level at lower voltage levels.

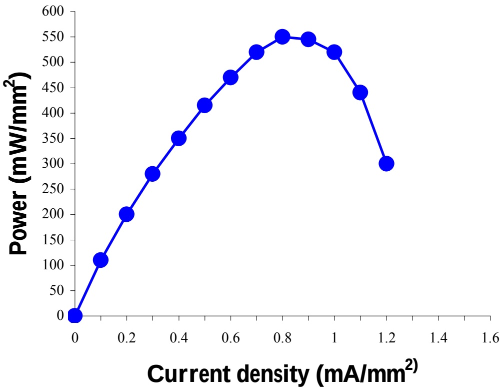

Figure 12 Power response curve.

D. *Methanol concentration*

The fuel to a Direct Methanol Fuel Cell does not consist of 100% concentrated methanol. It is in actual fact a dilution of 2 moles of methanol in distilled water.

Experimental voltage-current curves are given in figure 14. Similar work was done by Sundmacher et al. [5]. Their findings were that the mass transfer coefficient increases as the methanol concentration feed increases. With a low methanol concentration feed there is just not enough methanol diffusion available to keep up with the reaction rate. Therefore, region C is reached much quicker than with a higher methanol concentration. Sundmacher et al. [5] also state that the formation of CO_2 bubbles on the surface of the anode diffusion layer may play a role.

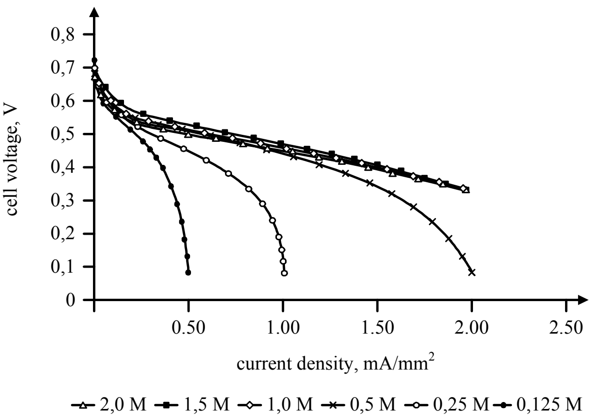

Figure 14 Different methanol feed concentrations.

E. Influence of temperature on a fuel cell

Fuel cell voltages and current densities are higher at higher operating temperatures. This can clearly be seen in figure 15. Work done by Scott et al. [2] show similar characteristics. The increase in temperature increases the electrochemical kinetics of the cell. Therefore, an increase in the voltage-current density curve is also observed. The temperature of the cell cannot be increased to high because this will damage the membrane. The membrane used in a DMFC is known as a proton exchange membrane (PEM).

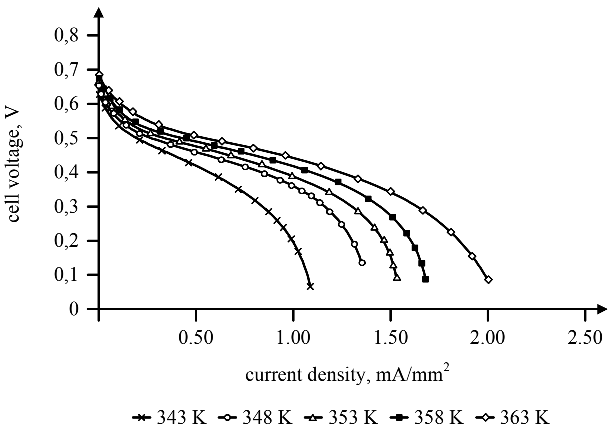

Figure 15 The effect of temperature on a fuel cell.

The DFMC has to be heated externally especially if higher operating temperatures are required. This will ensure that the cell has a higher efficiency. Heaters installed in the methanol solution can heat the stack to the required temperature. It was found that it is more effective to heat the methanol-water solution than to heat the flow field plates. The heated methanol solution is probably more effective because it comes in direct contact with the MEA.

F. Cathode oxidant flow rates

The air flow rate at the cathode is important. It also has an effect on the performance of the direct methanol fuel cell. If the cathode air flow rate is to low, the DMFC stack will be suffocated, if the flow rate is to high, the air blower will require more power from the stack to operate. The flow rate where the stack delivers the maximum current is called the stoichiometry of that specific stack. This depends on the design of the anode and cathode flow structure in the stack, operating temperature, cathode humidity and the pressure at which the system is operated.

A cathode air flow stoichiometry of one for this specific direct methanol fuel cell is defined as the air flow rate that will ensure for the stack to give its maximum performance. If the stoichiometry is decreased for example to 0,9 λ, the output of the DMFC stack will reach region C earlier. If the stoichiometry is increased 1,1 λ, the output of the stack will be the same as for a stoichiometry of 1 λ. Therefore, higher stiochiometries of one will have no effect on the increase of the performance of the stack.

V. CONCLUSION

All of the aspects discussed above are relevant to the design of a fuel cell stack that can be used as a power source. Therefore, researching and experimenting with these concepts can deliver a highly efficient direct methanol fuel cell power source that has very low pollutant emission levels.

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