Arcada Working Papers 15/2014
ISSN 2342-3064
ISBN 978-952-5260-57-1

Passive Fuel Tank for DMFC with Carbon Capture*

Björn Wiberg [i]

Abstract

An innovative new fuel tank was tested using a Direct Methanol Fuel Cell (DMFC). The aim of the fuel tank was to provide a fuel supply to the cell in all orientations while simultaneously capturing the carbon dioxide produced by the system in order to maintain a positive fuel pressure at all times.

Keywords: Fuel Cells, DMFC, Fuel Supply, Carbon Capture, Fuel Storage, Methanol

1 INTRODUCTION

The worlds growing demand for power has been for some time a pressing problem to the finitely limited natural resource. Not only is humankind faced with the problem that conventional resources are running out but also due to the fact that all the bi-products of these conventional resources are changing the planet we live on [1], having already increased the mean European temperature by 1.3°C since pre-industrial levels [2]; this problem goes further than most people realise as this creates a accumulating effect where any climate change encourages more climate change and as such once a tipping point is reached the detrimental process will be self-sustaining [3,4].

* This research has been made possible through the generous grant from Fonden för Teknisk Undervisning och Forskning (TUF).
[i] Arcada, Finland, Department of Energy and Materials Technology, [bjorn.wiberg@arcada.fi]

Suggestions such as sucking the CO_2 from the air [5] may seem ludicrous at the moment but is slowly moving towards becoming a need. Although it is argued [6] that CO_2 is in no way the only culprit to the modern day climate dilemma it has become the basis of all blame ranging from the taxing the CO_2 release from cars [7] to first world country responsibilities [8].

Even though the release of CO_2 is a major factor in our climate change conundrum it is not realistic that humanity cease to use all fossil fuel based energy sources simply overnight. While it is relatively simple to set up wind-farms or solar panels [9] on houses it does not provide enough energy to run our industries or even power cars, ships or airplanes. Currently lithium-ion batteries are doing the job of storing energy for the times when appliances cannot be connected to the main electrical grid but as a more environmentally conscious generation is coming to take over so are devices that have been normally run on fossil fuels (such as cars or buses) also increasingly being changed to electrical [10]. This in turn puts a huge stress on our current electrical network taking into account that most current electricity comes from power plants operating on fossil fuels such as coal, oil or gas.

This very limitation has led to a hybrid solution, it can be considered that any further advances with the internal combustion engine is rather minute and so the efficiency of these engines will never improve far beyond the current 25% or so [11]. Increasing the engine efficiency requires a completely new engine, one in which the device would produce electricity on the spot with a higher efficiency. For this electrochemical cells, or fuel cells, are seen as a viable alternative to the problem at hand.

Currently a large range of different fuel cells are available, each serving a different segment of the market, this makes the term fuel cell very broad as no single system will come out as being perfect for all applications. The one of current interest however is the DMFC.

The DMFC operates at low-temperature and uses a dilute methanol solution as its fuel source; as such it is ideal for the use in small electronics where large power output is not necessary. However due to its high catalyst loading it is hard to develop a cost effective DMFC. Variations of the DMFC exist such as the Direct Ethanol Fuel Cell (DEFC) which uses a dilute ethanol solution as its fuel as opposed to methanol.

1.1 Structure of DMFC

The DMFC fuel cell is made up of two primary components; primarily is the DMFC system enclosed within a casing and residing on top of the casing is a fuel tank that is directly connected to the anode of the fuel cell.

The shape and design of the fuel tank is a design taste rather than a technical one, though all components need to be in relative size to each other [12]. The tank needs to be directly connected to the anode in order to efficiently supply fuel. The fuel can then be feed to the anode directly or through capillary action [13]. The DMFC design does not require the use of any reformer or pump systems thus allowing a simple and compact design [14].

A DMFC does not need to be removed from an electronic device at any point (including refuelling) the option to remove the tank is also a design aspect rather than a technical one. The commercial industry has already been testing the method of refuelling a DMFC through injecting the fuel into an electronic device rather than changing the fuel tank [15]. This would allow electronic devices to function in much the same principle as modern cars. Once the level of the fuel reaches a critical limit the user only needs to top-up the tank. Changing tanks in DMFCs does not either require the electronic device to be turned off as the residual fuel left in the channels on the anode side will allow it to operate during the tank changeover time.

Using methanol as a fuel source is also a low cost alternative to other energy sources. Methanol can easily be bioengineered from organic sources such as waste re-cycling. It is readily available and has a low toxicity to humans, the energy density of methanol is 15.9 MJ/L (at 1 atm) compared to 2.75 MJ/L of hydrogen at 360 atm [16]. Though it is possible to feed a DMFC with other fuels than methanol, the methanol is preferred due to its simple structure allowing faster reaction kinetics on the anode catalyst surface of the MEA. The methanol concentration feed to the system can vary from 0.5 M methanol up to concentrated methanol solutions [17].

Water serves both a necessity and a detrimental function in DMFC; on the anode it is required while on the cathode it must be continuously removed. This however does provide an opportunity to create a mechanism where the water removed from the cathode is used to the dilute the methanol on the anode there by allowing for more energy to be stored in a smaller space [18-20].

1.2 Chemistry of the DMFC

The reactions of the DMFC on the anode side can be described as:

$$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$$

On the cathode side the reaction is completed:

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

Thus resulting in a total reaction of:

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

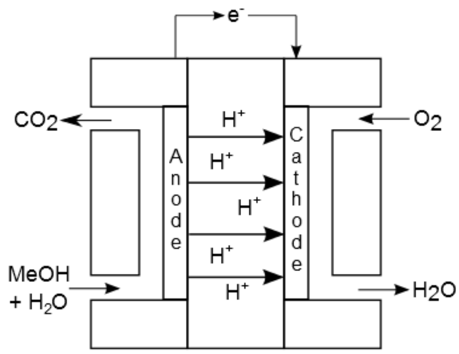

Figure 1: Schematic drawing of the mass transport in a DMFC system.

2 EXPERIMENTAL SETUP

The fuel tank is be made out of Polyethylene, allowing for a pliable and easily sealable material. As PE has a low melting temperature the tank can be sealed using heat as opposed to chemicals which damage the CO_2 absorbent.

In between the absorbent and fuel section of the tank a film will be placed in order to create a moving wall which reduces the under-pressure built up during methanol depletion. This membrane needs to be soft and flexible.

The bottom plate of the fuel tank is also fitted with four holes which will attach onto the MEA housing to create a tight fit. Out of these, two are designated for CO_2 capture and two of them for methanol injection to the DMFC. This is done by having two compartments inside the fuel tank, one leading to the absorbent and the other to the methanol. The capillary forces from the channels in the MEA housing will start the cycle of methanol flow.

In order to effectively test the capabilities of the fuel tank it was built and tested all in the same day.

3 RESULTS

Results from the test of the fuel tank showed clearly a working system. Using only 1 ml of fuel the tank was tested using an MEA produced by IRD. During testing a voltage of 0.22V was continuously drawn from the DMFC.

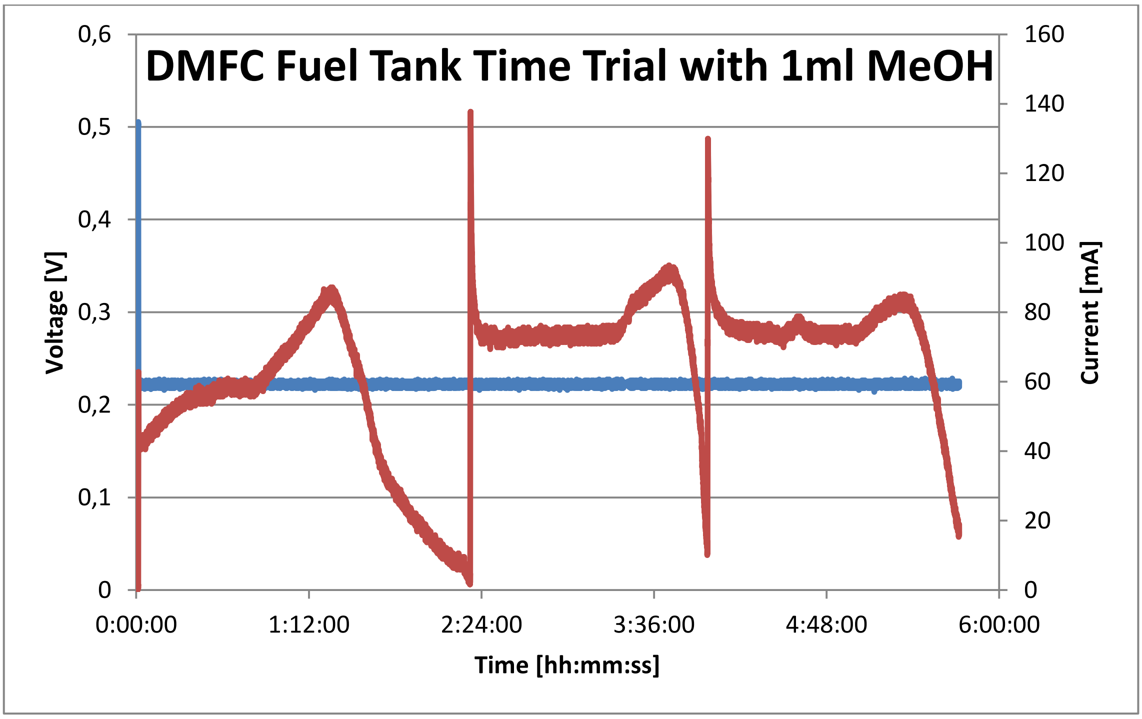

Figure 2: Time based measurement of a DMFC with a 1ml 2M methanol tank connected to it and refilled twice. Voltage is shown in blue and current in red.

In Figure 2 it can be clearly seen how the 1 ml of fuel gave 1.5 hours of continuous power output and then was quickly depleted as the fuel ran out in the tank. A re-fil of the tank can be seen at 2:24 and 3:57.

The re-fil also proves how the cell quickly recovers from no fuel to full capacity in a very short time frame.

The peak seen before the depletion of each fuel run is attributed to the expandable membrane having reached its full extent and pushing only on the fuel located at the outlet of the fuel tank causing an increase in the fuel pressure before running out.

4 CONCLUSIONS

The fuel tank worked as expected, creating a continuous overpressure ensuring that fuel was supplied to the anode of the fuel cell at all times. At the same time the cell operated at a constant power output till the fuel in the tank was almost depleted. This clearly proves the concept of using a carbon capture fuel tank for DMFC as a viable option not just for reducing the CO_2 produced by the DMFC but also by utilising the exhaust in a manner that benefits the system as a whole.

REFERENCES

[1] J Hansen, M Sato, R Ruedy, K Lo, DW Lea, M Medina-Elizade. Global temperature change, Proceedings of the National Academy of Sciences. 103 (2006) 14288-14293.

[2] Global and European temperature (CSI 012/CLIM 001) - Assessment published Jun 2012, 2012.

[3] DS Kaufman, DP Schneider, NP McKay, CM Ammann, RS Bradley, KR Briffa, et al. Recent Warming Reverses Long-Term Arctic Cooling, Science. 325 (2009) 1236-1239.

[4] FM Hopkins, MS Torn, SE Trumbore. Warming accelerates decomposition of decades-old carbon in forest soils, Proceedings of the National Academy of Sciences. 109 (2012) E1753-E1761.

[5] M Marshall, Geoengineering trial hailed a success, NewScientist. (2012) 15.

[6] J Hansen, M Sato, R Ruedy, A Lacis, V Oinas. Global warming in the twenty-first century: An alternative scenario, Proceedings of the National Academy of Sciences. 97 (2000) 9875-9880.

[7] Fordonsskattelag 30.12.2003/1281, Finlex. (2003).

[8] T Wei, S Yang, JC Moore, P Shi, X Cui, Q Duan, et al. Developed and developing world responsibilities for historical climate change and CO2 mitigation, Proceedings of the National Academy of Sciences. (2012).

[9] Lysande framtid för solceller, Illustrerad Vetenskap. 11 (2012).

[10] SF Tie, CW Tan. A review of energy sources and energy management system in electric vehicles, Renewable and Sustainable Energy Reviews. 20 (2013) 82-102.

[11] G Singh, DOE Transportation Strategy:Improve Internal Combustion Engine Efficiency, (2011).

[12] B Bennett, BM Koraishy, JP Meyers. Modeling and optimization of the DMFC system: Relating materials properties to system size and performance, J.Power Sources. 218 (2012) 268-279.

[13] M Yonetsu, JP Yokohama, Liquid fuel-housing tank for fuel cell and fuel cell, US 6506513 (2003).

[14] AK Shukla, PA Christensen, AJ Dickinson, A Hamnett. A liquid-feed solid polymer electrolyte direct methanol fuel cell operating at near-ambient conditions, J.Power Sources. 76 (1998) 54-59.

[15] Y Chan, Toshiba unveils methanol fuel cell recharger for mobile gadgets, businessGreen.com. 2012 (2009).

[16] B Gurau, ES Smotkin. Methanol crossover in direct methanol fuel cells: a link between power and energy density, J.Power Sources. 112 (2002) 339-352.

[17] T Tsujiguchi, MA Abdelkareem, T Kudo, N Nakagawa, T Shimizu, M Matsuda. Development of a passive direct methanol fuel cell stack for high methanol concentration, J.Power Sources. 195 (2010) 5975-5979.

[18] M Ali Abdelkareem, N Nakagawa. DMFC employing a porous plate for an efficient operation at high methanol concentrations, J.Power Sources. 162 (2006) 114-123.

[19] Z Guo, A Faghri. Vapor feed direct methanol fuel cells with passive thermal-fluids management system, J.Power Sources. 167 (2007) 378-390.

[20] A Faghri, Z Guo. An innovative passive DMFC technology, Appl.Therm.Eng. 28 (2008) 1614-1622.