RJBS
Romanian Journal of Building Services
Revista Română de Instalații
Volume 1 / No. 3 / 2015 / www.rjbs.ro

Conceptual Reduced Cost PEM Fuel Cell Design for Domestic Applications

Mohamad Y. Mustafa – Narvik University College, 8505 Narvik, (Norway)
Email : myfm@hin.no

Rajnish Calay – Narvik University College, 8505 Narvik, (Norway)
Email : rkc@hin.no

Abstract: Fuel cells are energy converters which have the ability of converting the chemical energy of fuel, mostly hydrogen, into electricity through an electrochemical process without the need for combustion. This paper aims at reducing the cost of fuel cell manufacturing through simplifying the design and using less exotic materials. Components of the fuel cell which are costly in terms of materials cost and machining are the bipolar plates and end plates, which are conventionally made of graphite. Flow channels in the graphite plates are usually made through machining with different configurations, which increases the overall cost, depending on the complexity of the topography of the channels. A novel design of a fuel cell stack is presented. A significant shift from conventional FC design in the proposed design approach is to separate the two tasks of the bipolar plate, namely gas distribution and interconnection of the fuel cells. The second step is to change the internal configuration of the fuel cell to reduce the number of electrode plates and gas distributors. This design is suited for domestic application due to its modular features, easy maintenance and reduced cost and volume. Details of the fuel cell design, together with test data based on the proposed design as well as comparison data from a conventional fuel cell are presented and discussed.

1. Introduction

Fuel cells (FC) are emerging as power plants for the future, due to the desire to reduce the impact of harmful emissions. There are many positive signs which support this orientation, the main development is the commercialization of Hydrogen fueled vehicles by major vehicle manufacturers around the world. This is also supported by the growing interest in establishing hydrogen-fueling stations to provide for the upcoming spread of hydrogen cars. In addition to automotive applications, fuel cells are being designed for aerospace, military applications, domestic and stationery power and small electronics appliances.

Nevertheless, progress towards commercial utilization of fuel cell technologies is still slow when compared to their main competitor, the internal combustion engine. Several progresses have been made in new materials, and manufacturing techniques in the past decade, however FC still demands significant technological advancements to achieve cost reduction and increased durability, to allow full exploitation of FC technology.

There are five major types of FCs based on the type of electrolyte used; polymer electrolyte membrane (PEM), solid oxide fuel cell (SOFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC) and molten carbonate fuel cell (MCFC). Operating temperature for each FC type is different and varies from low temperature of 80 ^oC for PEMFC to as high as 1000 ^oC for the SOFC.

However, the working principle of all FCs is similar, as they directly convert chemical energy in a fuel to electrical energy through an electrochemical reaction without combustion. In this process, no harmful emissions are produced if the fuel used were hydrogen, as the only byproduct in this case is water, however, carbon oxides are produced if the fuel used contains carbon, such as methane or methanol, and Nitrogen oxides in the case of high temperature furl cells, but to a much lesser extent than internal combustion engine. Fuel cells are also characterized by their high efficiency and low noise emissions due to the absence of moving components, except for balance of plant components, which usually have low noise emissions.

In a PEMFC device, ions are transferred through a membrane, while electrons are forced to flow around an external electric circuit. Due to its low temperature and easy start-up, PEMFC is the most preferred FC type for many applications including domestic and automotive.

2. Proposed design concept

The main design specifications for the proposed experimental fuel cell are:

a) A PEM Fuel Cell for stationary domestic applications. The fuel cell can be mounted as an integral part of the building structure (e.g. built in to the wall) or wall mounted (similar to a gas boiler).

b) The fuel cell output should be sufficient for household requirements (5 kW net output) and voltage output which can be modified to match the grid voltage (220 V or voltage and current values that can be inverted to grid voltage).

c) The fuel source is pure hydrogen from a compressed hydrogen cylinder. However, hydrogen can be provided from a reformed natural gas source, provided the carbon emissions are treated to prevent harm to inhabitants or fuel cell components.

d) The oxidant is ambient air or pure oxygen.

In order to achieve the required voltage output, single fuel cells are connected in series in a stack, the connection can be achieved internally, using bipolar plates (BPP), or externally by wiring each cell to the adjacent cells.

BPPs and end plates are usually made of graphite. They constitute nearly (30%) of the total estimated cost and nearly (80%) of the volume of the fuel cell. BPPs distribute the gases over the surface of the membrane and serve as electrodes, which transport the electrons from anode to cathode, while connecting individual fuel cells in series to form a fuel cell stack capable of delivering the required voltage output. Conventionally, plates' material is chosen, machined or treated to satisfy both requirements at the same time.

Considerable reduction in fuel cell cost can be achieved if the functions of the bipolar plates were treated individually and different materials were used to satisfy each requirement independently. Furthermore, the cost can be reduced further by reducing the number of components. This can be achieved by changing configuration of the fuel cell. The common approach is to connect the cells in series internally using the BPPs as the connecting medium, this is actually where the term bipolar plate comes from; the cathode of one cell is connected to the anode of the adjacent cell [1].

The number of those plates can be reduced, if one gas distributor was used to supply hydrogen or oxygen to two cells at the same time, hence changing configuration of the FC so that one gas distributor is used to supply reactant gas to two anodes, or two cathodes at the same time. The configuration of the FC in the conventional design is: (Anode - Cathode – Anode ... etc.); the proposed configuration is: (**Anode – Anode – Cathode – Cathode ... etc**.), as shown schematically in figure 1.

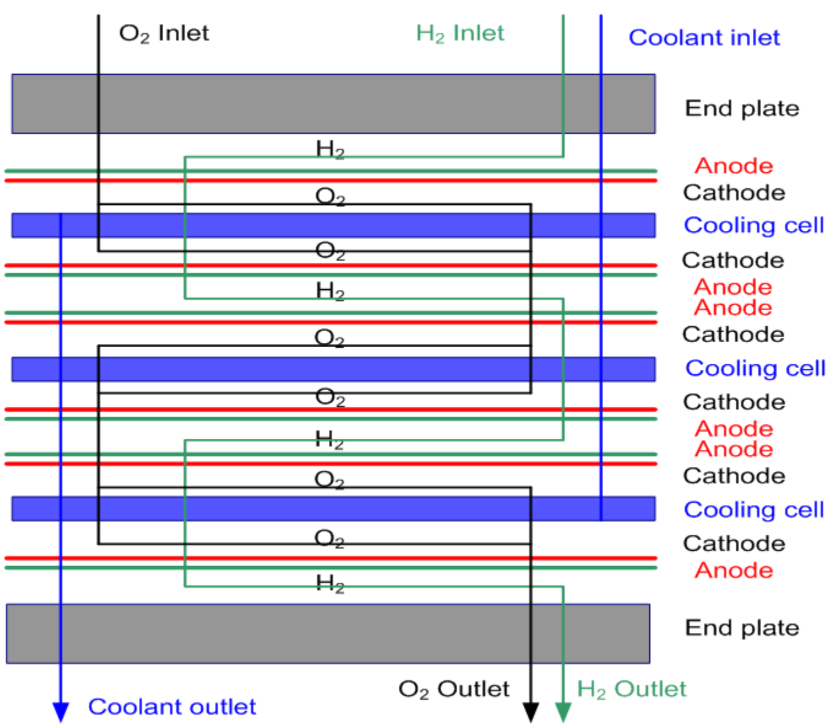

Figure 1 Schematic of FC design concept indicating gas flow and electrode arrangement

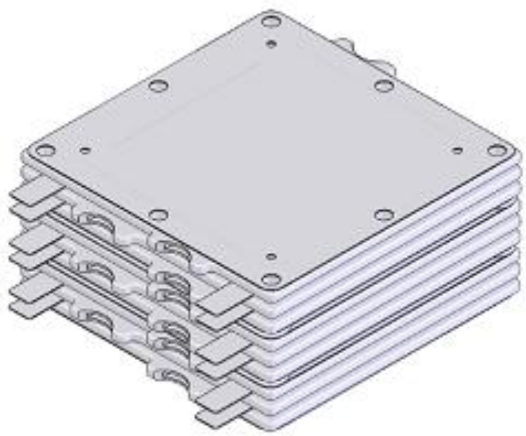

Figure 2 100 W fuel cell module based on the proposed design concept. Fuel, oxidant and cooling ports are at the side

In this approach, electrode plates are based on perforated high-chromium content stainless steel, to reduce the effect of electrical resistance on the fuel cell performance; perforations should be restricted to the active area only [2]. This allows for external series or parallel electrical connection of the cells, which further simplifies the design and gives more flexibility to output customization. A six-cell 100 W plug-in fuel cell module based on this design concept is shown in figure 2 [1].

The proposed design increases robustness and compactness of the FC, due to the endurance of stainless steel under machining and operating conditions. Furthermore, it simplifies maintenance and complexity of the design as membrane and stainless steel electrodes can be manufactured as a single sealed unit, which reduces the cost of manufacturing [1].

3. Experimental data

A comparison between 3 fuel cells designed on the basis of the concept proposed in this work and compared to a conventional FC is presented in the polarization curve, figure 3 [1].

FCs were operated under the same operating conditions and using the same type of membranes. Performance of the stainless steel FC is, qualitatively lower than the graphite FC, most likely due to formation of oxidative layer on the stainless steel under the acidic conditions of the FC environment. However, compactness, robust design features and flexibility in operation were demonstrated during manufacturing and testing [1].

The linear portion of the three curves, as seen in figure 3 has almost the same slope as the graphite based fuel cell. This is an indication that the voltage losses due to resistances in the fuel cell are not more pronounced than those in the graphite plate fuel cell, but the poorer performance is mainly due to the initial shift of the curve to the low voltage region due to activation losses. Nevertheless, the results of the experiments indicated the potential of the new fuel cell design for practical implementation, and for considerable reductions in fuel cell cost.

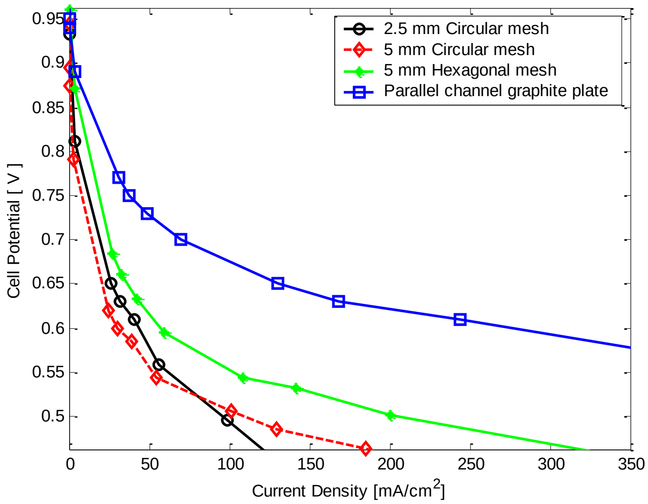

Figure 3 Test data for 3 meshed stainless steel electrode FCs and single conventional FC. Op. conditions 92% RH, 60°C

4. Conclusions

There is considerable potential for the improvement of the fuel cell design to reduce the cost and improve the performance through the use of common materials and design techniques. The modular design presented in this paper presents a simple fuel cell design, which reduces the cost of production and compares to the performance of the state of the art fuel cells.

A novel FC design based on perforated high-chromium content stainless steel was discussed in this work. This design provides flexibility to output customization. It also increases robustness, compactness, and simplifies maintainability of the FC system. The cost of manufacturing can be reduced further by producing the membrane and stainless steel electrodes as a single sealed unit. Experimental data indicated that the proposed design performed well when compared to conventional graphite based fuel cell but still needs further improvements [1].

5. References

[1] M. Y. Mustafa, "Design and manufacturing of a. (PEMFC) proton exchange membrane fuel cell," PhD. Thesis, Coventry University, May 2011. [Online]. Available: https://curve.coventry.ac.uk/open/file/272310c1-2614.../mustafacomb.pdf. [Accessed August 2015].

[2] Wang, Y. and D.O. Northwood, " An investigation into the effects of a nano-thick gold interlayer on polypyrrole coatings on 316L stainless steel for the bipolar plates of PEM fuel cells.," *Journal of Power Sources,* vol. 175, no. 1, pp. 40-48, 2008.