M1-007 Comparative study of Solid Oxide Fuel Cell and Proton Exchange Membrane Fuel Cell

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Abstract

Fuel cells are set of components that convert the chemical energy of fuel into electrical energy directly through the electrochemical reactions. These components comprised of anode, cathode and electrolyte. Due to depleting in fossil based fuel in the world as well as the world energy crisis, has created major concerns in many countries in finding the alternative renewable energy. Fuel cells are one of the potential solutions available which produce a clean technology; less pollutant and less carbon dioxide emitted. Although the fuel cell technology has been commercially available, many investigations are still been carried out. The challenges include reducing the expensive cost for electrolyte materials and process as well as to develop the infrastructures. This paper is intended to compare two types of current fuel cells technology that are Solid Oxide fuel cell and Proton Exchange Electrolyte Membrane fuel cell.

Keyword: Fuel cell, SOFC, PEMFC

1.Introduction

Decreasing in fossil based fuel and world energy crisis have led many investigations concerning to renewable energy. One of the promising energies that have been investigated is fuel cell. The advantages of fuel cell are related to its capability to convert the chemical energy from fuel into electrical energy through electrochemical process, as well as green environments[1,2,3,4]. Several fuel cells have been explored including the likes of Alkaline fuel cell (AFC), Molten Carbonate fuel cell (MAFC), Phosphoric Acid fuel cell (PAFC), Polymeric or Proton Exchange Membrane fuel cell (PEMFC) and Solid Oxide fuel cell (SOFC). The AFC, MAFC and PAFC use the liquid electrolyte to transfer the ions from one electrode to another, whereas the PEMFC and SOFC use a dense or solid electrolyte for the same purposes [5,6,7].

Generally, the fuel cell comprised of three main components; anode, cathode and electrolyte as demonstrated in Figure 1. Principally, oxidant (oxygen or air) supplied from the cathode reacts with fuel (H_2, CH_4, CH_3OH) from anode to produce current and reactant products such as steam water and heat [8]. This paper discusses the comparison between the PEMFC and SOFC in terms of electrochemical reactions, material used and also the manufacturing processes

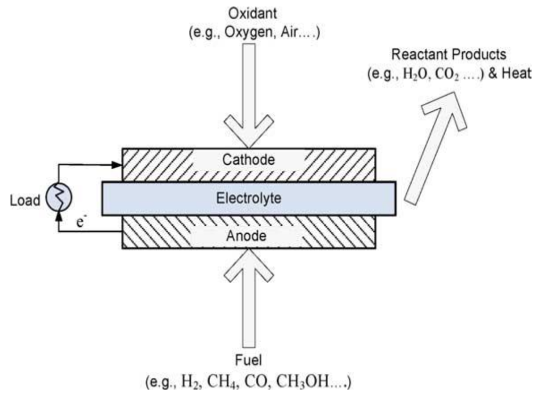

Fig1. Component of fuel cell [8]

2. Electrochemical Reaction

For an electrochemical reaction to take place, there are three vital components, e.g. electrodes, electrolyte and external connection. Without any one of these components, the reactions could not be operated. The electrochemical reactions normally occur on the anode and cathode electrode surfaces, involving both oxidation of anode and reduction of cathode. This pair is often referred as a redox reaction. Electrochemical reductions consume electrons, reducing the valence state, whereas electrochemical oxidation resulted in electron losses thus increasing the valence state [6,7].

The main function of the electrolyte is to transfer ions from one electrode to another. This electrolyte can be a liquid or a solid, serves to physically separate the fuel and the oxidiser, as well as to prevent electron short-circuiting between electrodes. The final component that is the external connection links between the two electrodes to allow for current flows [6,9]. Figure 2 shows a basic electrochemical reaction process .

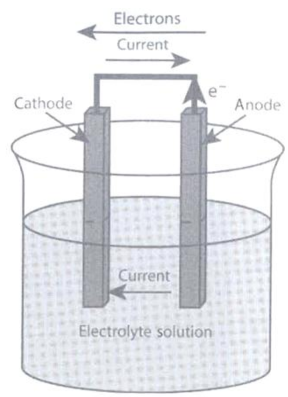

Fig.2. Basic reaction circuit [6]

In a fuel cell, the hydrogen combustion reaction is split into two electrochemical half reaction, [6,7,8,10,11]

$H_2 \leftrightarrow 2H^+ + 2e^-$ (1)

$\frac{1}{2} O_2 + 2H^+ + 2e^- \leftrightarrow H_2O$ (2)

The global oxidation and reduction that occurs at the anode and cathode of fuel cell with acid or alkaline electrolytes:
For acid electrolyte that transport positive ions through the electrolyte such as PEMFC,
Anode global hydrogen oxidation reaction (HOR) :

$H_2 \rightarrow 2H^+ + 2e^-$ (3)

Cathode global oxygen reaction (ORR) :

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (4)

For alkaline electrolytes that transport negative ions through the electrolyte such as SOFC :

Anode HOR : $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ (5)

Cathode ORR : $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (6)

Reaction in acid electrolyte is not occurred directly but through steps as follow,

$H_2 \leftrightarrow 2(H - M)$ (7)

$(H - M) \leftrightarrow H^+ + e^-$ (8)

in these equation, M represent the non reacting catalyst surface and usually from metal platinum (Pt). Reaction which may be occurred in three possible reaction [10]:

$Pt \rightarrow Pt^{+2} + 2e^-$ (platinum dissolution) (9)

$Pt + H_2O \rightarrow PtO + 2H^+ + 2e^-$ (10)

(platinum oxide film formation)

$Pt + 2H^{+2} \rightarrow Pt^{+2} + H_2O$ (11)

(Chemical dissolution of platinum oxide)

Currently research PEMFC and Direct methanol Fuel Cell (DMFC), using of platinum as catalyst, gradually decrease because price expensive and stock available limited. Result experiment which use catalyst $Pt_{75}Co_{25}/C$ and Pt/C show that performance cell potensial $Pt_{75}Co_{25}/C$ more better compare with Pt/C.[10] Also performance of PEMFC is affected by humidification, temperature and pressure[3,12,13]
While electrode in SOFC did not use nobel non reacting catalyst to proceed electrochemical reaction, so this condition will reduce cost of electrode. Performance of SOFC also depends on the type material which use as electrolyte and temperature operation.[14,15,16]

3. Material

One single PEMFC comprised of four elements, namely as diffusion media (DM), micro-porous layer (MPL), catalyst layer (CL) and membrane, stacked by another single PEMFC as shown in Figure 3

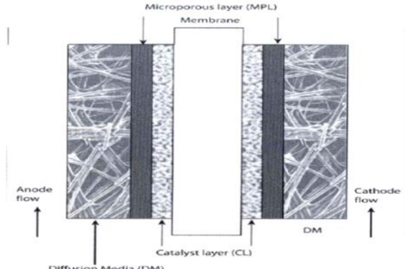

Fig3. Schematic PEMFC [6]

DM is a woven cloth or non-woven fibre/ felt structure, held in a carbonized resin binder to provide good electrical conductivity. MPL consists of 5 to 20 percents of carbon particle, 5 to 20 percents of polytetraflouroethylene (PTFE) and polymeric binder. CL is made of platinum, PTFE and carbon. PEMFC use solid polymer electrolyte to transport ions from the anode to cathode electrodes. In general, nafion is mainly selected as the electrolyte material. A seal made of silicone elastomer is used as a sealant to protect from gas leaking off the stack system [17].

In SOFC, various materials can be chosen for anode, electrolyte and cathode, following their respective design requirements. Currently, several materials have been used to produce the anode including nickel-based, copper-based, lanthanum-based, cobalt-based and platinum-based materials. Design requirements for the anode are [18,19] :

- electrically conductive,
- possess higher electrocatalytic activity,
- chemically stable in reducing environment
- able to provide mechanical support to electrolyte and cathode
- able to avoid cake deposition
- large triple phase boundary
- production as a uniformly thin layer (to minimise mass transfer losses)
- tolerant to sulphur in fuels
- able to withstand low vapour pressure
- able to provide direct internal reforming
- able to provide pressure
- uses relatively inexpensive materials
- uses relatively inexpensively materials

Several materials have also been used for electrolyte, e.g. zirconia-based, Ceria-based, Yttria-based, lanthanum-based and also bismuth-based materials. Specifically, in zirconia-based materials, examples are yittria stabilized zirconia (YSZ) and Scandia stabilized zirconia. In ceria-based materials, there are Gadolina doped ceria (GDC), samaria doped ceria (SDC) and Yttria doped ceria (YDC), whereas lanthanum strontium gallium magnesium oxide (LSGM), lanthanum strontium gallium magnesium cobalt oxide (LSGMC) are examples for lanthanum-based materials. In general, all of these materials meet the design requirements for electrolyte fabrication as follows [18,19]:

- ionically conductive (should be characterized by oxygen ion transport numbers close to 1),
- electronically insulating,
- chemically stable at high temperature,
- chemically stable in reducing and oxidizing environments,
- gas tight/ free porosity,
- production as a uniformly thin layer (to minimize ohmic losses),
- thermal expansion that matches electrode,
- Uses inexpensive materials.

Normally SOFC is operated at 800^o C – 1000^o C using YSZ material as electrolyte. However, there are some common efforts which focus on a lower temperature SOFC to compensate the available materials. For example, it was found that samaria doped ceria (SDC) of ceria-based material exhibits higher ionic conductivity when operated under 700^o C [18] whereas YDC electrolyte was well used when paired with YDC/Ni anode at the temperature of 650^o C [15].

Cathode material or the air or oxygen electrode is the site where oxygen is reduced to oxide ions within each cells. The cathode usually functions as the support during fabrication of tubular cells. Various types of materials are possible for cathode materials. Material which is normally used as cathode is lanthanum-based cathode, i.e. lanthanum strontium mangan oxide (LSM), lanthanum strontium ferum oxide (LSF) and lanthanum strontium cobalt oxide (LSC) materials. Others, Gadolinium-based cathode such as gadolinium strontium cobalt oxide (GSC), gadolinium strontium mangan oxide (GSM) are also used. Following design requirements for the cathode are [18,19] :

- high electronic conductivity,
- chemically compatible with neighbouring cell component (usually the electrolyte),
- can be made thin and porous (thin enough to avoid mass transfer losses, but thick enough to provide area and distribute current),
- stable in oxidizing environments,
- catalyze the dissociation of oxygen,
- high ionic conductivity,
- adhesion to electrolyte surface,
- thermal expansion coefficient similar to other SOFC materials,
- relatively simple fabrication,

The remaining lanthanum cathode materials have shown varying success in conductivity and stability improvements over LSM and LSF. Specifically, LSC is a candidate for lower temperature stack with higher conductivity than LSM and one of better power densities when couple with LSGM electrolyte [12,18-19].

In planar SOFCs, seals attach the cell to the interconnector and/or metal frames as well as seal all possible leakage points. In general, material for seals can be divided into three categories: rigid bonded seal as glass (Pyrex) or glass-ceramic materials, compressive and compliant bonded seal. However, compressive and compliant bonded seals are less common. Compressive seals are generally mica composite with the advantage of being potentially easy to fabricated, usually from the avoidance of the viscous/ sealing step [12,19-21]]. In short, design requirement for the seals are as follows [19,22-25]:

- electrically insulating,
- low cost,
- thermal expansion compatibility with other cell components,
- chemically and physically stable at high temperature
- gas tight,
- chemically compatible with other component,
- able to provide high mechanical bonding strength.

4. Manufacturing

Since last decade, the fabricated fuels cells have been mainly used in various applications depend on the power requirement. For examples, portable applications required the fuel cell to be designed and produced the power in the range of 0.5 – 20 W, whereas in transportation, about 65 kW of power is required [2,26-28]. This shows that every application require different power consumption and requirement. Siemens-Westinghouse has produced the fuel cells up to 250 kW [18,19]
Principally, the fuel cell is developed from several single cells, connected in series or parallel configuration similar to electrical circuit. Various techniques of manufacturing process are available for PEMFC and SOFC

Principally manufacturing of cell develop from single cell which connected though series or parallel likes electrical circuit. There are many manufacturing of single cell for PEMFC or SOFC and available two type of stack that is planar type and tubular type of fuel cell.

Fig 4 . Planar type fuel celland and Fig 5. Tubular type fuel cell

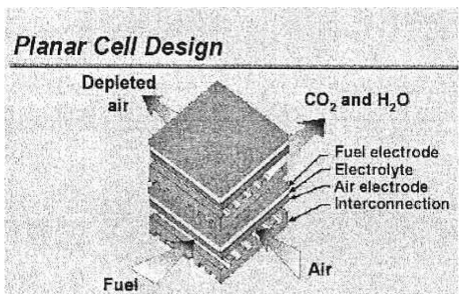

Fig 4. Planar type fuel cell [19]

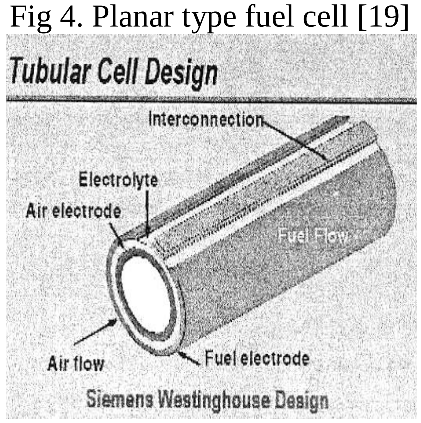

Fig 5. Tubular type fuel cell [19]

The choice of the type depends on the design needs, the flattened tubular which have been developed by siemens-westing house, have high power density while the planar type have higher cell power density [18].

PEMFC manufacturing include 1. spray deposition. This method can be used to produce diffusion media (DM).

A slurry of catalyst, support, PTFE, solubilized polymer ionomer and alcohol compounds (to taylor the slurry viscocity) are sprayed directly onto the DM or electrolyte surface. Fig.3. show the detail components. The spray can be applied by a simple nozzle or via electrodeposition, sputter deposition.[12,26-27]. The slurry is then held at high temperature in an oven to evaporated the remaining alcohols. This method has advantage of being relatively rapid, but tolerance are not precise compare to other methods. 2. Slurry tape casting. In this method a slurry or a catalyst layer ink similar to that used in spray deposition technique is spread onto the DM or directly the electrolyte via a doctor blade [7]. This method produce high dimensional tolerance but is slower than physical spray deposition and less suitable for mass production. The slurry tape casting also can be used for electrolyte membrane. 3. Decal method. In this technique, thin CL are cast or spread onto nanoadhesive medium, and decal transferred onto electrolyte by hot pressed compression (similar to clothes iron) [7,26]. This method is suitable for mass production of catalyst layers, with high tolerance and batch processing capability, although the physical bond between the electrode and electrolyte must be carefully maintained. [7,12,26-27]
Manufacturing of Solid Oxide fuel cell is available in several method such as cold compaction, chemical vapour deposition, electrochemical deposition, extrusion, sol gel, tape casting, slurry spraying, wet powder spraying.[14,16,21-22,29,30]

Among the processes above for sofc, some are not as promising as others when commercialization is considered. For example, the use of compaction, electrochemical vapour deposition, physical/sputtering vapour deposition (PVD), sol gel and roll calendaring process require either development or are not viable [18]. Also, not all process have been applied to all component and for all materials SOFC. For example component electrolyte using material YSZ can be process by chemical vapour deposition, screen printing , slurry spraying , slip casting , tape casting. From this condition can be decided tape casting more viable for mass production while CVD more precision but more expensive [18,19].

5. Conclusion

As a conclusion, several parameters between PEMFC and SOFC have been discussed. Several issues can be highlighted that:

1) PEMFC and SOFC have same type of dense electrolyte. PEMFC used electrolyte made of polymer material whereas SOFC used ceramic material.
2) SOFC is not affected by the content of CO gas, but PEMFC does. For fuel content more than 105 ppm, the performance of PEMFC is affected by CO gas [11].
3) Maximum operation temperature for both PEMFC and SOFC is different. PEMFC operated at a lower temperature, and max about 120 ^{o} C, whereas SOFC can be operated at higher temperature in range of 600 – 1000^{o} C [1-3,15-16,18-19,26].This shows that SOFC is high temperature resistance. In contrast, the steam water produced at a lower temperature affect the performance of PEMFC.
4) PEMFC is suitable for mobile power supply such as mobile phone, whereas SOFC is more suitable for stationary power supply. Therefore SOFC is suitable for power generator that can improve its total efficiency [26]
5) In terms of manufacturing process, tape casting method is suitable in producing single cell of PEMFC and SOFC as well as for mass production.

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