# Design and Development in Thermal Management of Fuel Cell

Kare K. M.*, Chormal S. B.[1], Choudhari V. M.[2], Dhaktode S. H.[3], Markad R. G.[4]
*Asst. Professor,
[1,2,3,4] Student of Mechanical Engineering,
SBPCOE, Indapur-413106 MH, India.

***Abstract*:- Fuel cells are electrochemical devices which convert chemical energy in electrical energy. Development and application of fuel cell technology will be increased significantly through analysis and improvement of the heat transfer in the fuel cell stack and auxiliary components and by implementation of innovative heat transfer schemes that address those issue. A point by point audit of these issues identified with power module innovation, including as of late creating difficulties, is introduced. Energy components have stood out because of their potential as promising option in contrast to customary power assets. A mix of novel techniques, expanded productivity of segments, diminished part size and mass and itemized demonstrating. Energy unit innovations and engineers, power device models, and uncertain issues in power device demonstrating. Development and application of fuel cell technology are be exaggerated considerably through analysis and improvement of the heat transfer within the cell stack and auxiliary parts and by implementation of innovative heat transfer schemes that address those problems. a detailed review of those issues associated with cell technology, including recently developing challenges, is presented. Current technical limitations may be overcome through mixmethodologies, increased potency of parts, decreased p art size and mass, and detailed modeling. This paper additionally outlines the existing cell technologies and developers, cell models, and unresolved problems in fuel cell modeling. A basic issue speaks to a sufficient warm administration and request situated cooling of FCEVs to maintain a strategic distance from wellbeing issues, corruption and a lessening in efficiency during activity.***

***Keywords: Fuel Cell, Hydrogen, Oxygen, Cathode, Anode.***

## INTRODUCTION

### *1.1 History*

The idea of a power device had viably been exhibited in the mid nineteenth century by Humphry Davy. This was trailed by spearheading take a shot at what were to progress toward becoming power devices by the researcher Christian Friedrich Schönbein in 1838. William Grove, a scientist, physicist and legal counsellor, is commonly credited with designing the power device in 1839. In 1932, Cambridge designing educator Francis Bacon altered Mond's and Langer's hardware to build up the first AFC however it was not until 1959 that Bacon exhibited a down to earth 5 kW power device framework. At around a similar time, Harry Karl Ihrig fitted a changed 15 kW Bacon cell to an Allis-Chalmers agrarian tractor. Allis-Chalmers, in association with the US Air Force, thusly built up various energy component fueled vehicles including a forklift truck, a golf truck and a submersible vessel. The 1970s saw the development of expanding ecological mindfulness among governments, organizations and people. Significant specialized and business improvement proceeded during the 1980s, eminently in the zone of PAFC. A brilliant future for the innovation was broadly anticipated around this time for stationary applications and transports. Consideration went to PEMFC and SOFC innovation during the 1990s, especially for little stationary applications. Energy units started to end up business in an assortment of uses in 2007, when they began to be offered to end-clients with composed guarantees and administration ability, and satisfied the codes and guidelines of the business sectors where they were sold. In the course of the most recent five years, as appeared in the information tables in this Review, development in shipments of energy units has quickened quickly as different applications have turned out to be business. Compact power devices saw the most fast pace of development over the period since 2009.

### *1.2 Fuel cell*

A fuel cell is an electrochemical energy device that converts the chemical energy in the fuel directly into electrical energy. Unlike conventional power devices, i.e., steam turbines, gas turbines and internal combustion engines, which are based on certain thermal cycles, the maximum efficiency of fuel cells is not limited by them Carnot cycle principle[1]. A fuel cell generally functions as follows: electrons are released from the oxidation of fuel at the anode, protons (or ions) pass through a layer of electrolyte, and the electrons are required for reduction of an oxidant at the cathode. The desired output is the largest flow of electrons possible over the highest electric potential.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

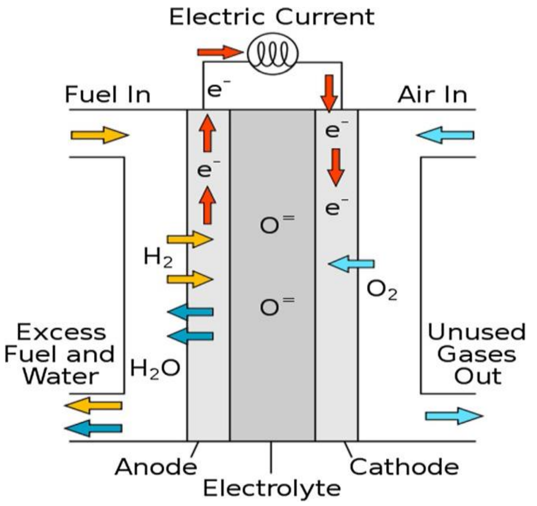



Fig. 1.1.1 Proton Exchange Membrane [Ref. by Hamideh Vaghari]

Schematic representation of a solid oxide fuel cell show in figure.Although other oxidants such as the halogens have been used where high efficiency is critical, oxygen is the standard because of its availability in the atmosphere. Fuel cells typically use hydrogen, carbon monoxide or hydrocarbon fuels (i.e., methane, methanol). The hydrogen and carbon monoxide fuels may be the products of catalytically processed hydrocarbon. Hydrogen from processed ammonia is also used as fuel. [2]

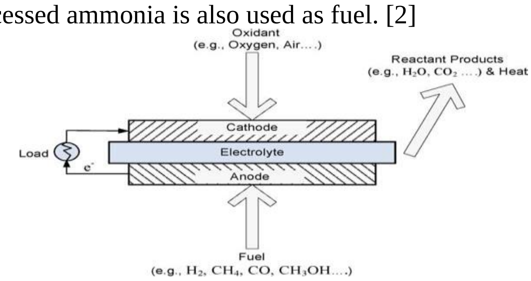



Fig. 1.2.1:General fuel cell [Ref. by Amir Faghri]

### *1.3 Thermal management*

A simplified schematic of the fuel cell thermal management system is shown in Fig.1.31. The stack coolant inlet temperature and the coolant flow-rate are the two main factors that affect the heat supplied or removed from the fuel cell stack, and hence the stack temperature. The coolant flow rate is controlled by an electric pump, while the coolant inlet temperature is regulated by appropriately flowing the coolant through a radiator or a heater, where the flow path is selected by a 2-position 3-way valve. Thus the system dynamics is hybrid in its nature.

Operating temperature affects the maximum theoretical voltage at which a fuel cell can operate. Higher temperatures correspond to lower theoretical maximum voltages and lower theoretical efficiency. However, higher temperature at the electrodes increases electrochemical activity, which in turn increases efficiency[3].Operating at a higher temperature also improves the quality of the waste heat.

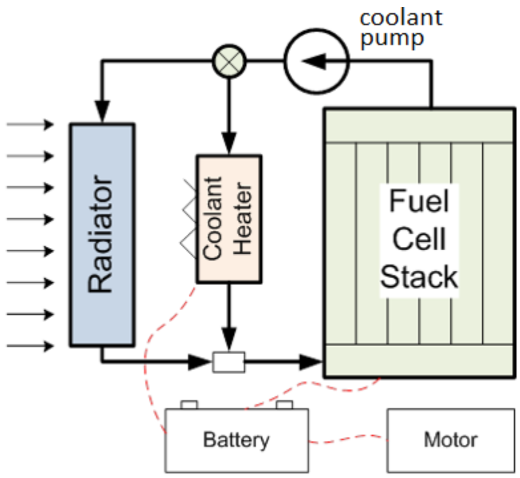



Fig. 1.3.1: Layout of fuel cell thermal management system

It should be noted that there is a moderate temperature range within which a specific type of fuel cell can operate well and reliably. The main purpose of thermal management in fuel cell systems is to ensure stack operation within the specific temperature range. Optimal thermal management also allows for effective use of the fuel cell systems by product, heat, leading to substantial increases in overall system efficiency. For example, a fuel cell operating at 1.0 kW and 50% efficiency generates 1.0 kW of waste heat. This heat may be dissipated by convection, conduction, radiation or phase change. The heat generated in a fuel cell stack may be dumped to the atmosphere, but often it is used in other system components requiring heat. In some cases the heat is used to run a thermodynamic cycle for additional show how many processes requiring heat and mass transfer are present in a fuel cell. This system consists of a number of support components, including some exothermic devices that produce heat while in use and require cooling and endothermic devices that require heat to be operational. A PEM fuel cell stack used in this system is fed by hydrogen-rich gas from a methanol reformer. The low PEM fuel cell operating temperature (_100 _C) energy recovery system [4-8].

Power generation limits the availability of the waste heat from the stack. A novel cooling system was incorporated into the fuel cell system to efficiently recover this low temperature heat as described later. In the methanol tank, the methanol is pumped into a mixing chamber and mixed with liquid water pumped from a water tank at an appropriate ratio. The pressure of the resulting mixture is substantially reduced after flowing through an expansion valve. Subsequently, the mixture enters a heat exchanger or evaporator and is vaporized whileabsorbing heat from the coolant of the fuel cell stack cooler. This preheated mixture enters the methanol reformer and reacts0to form hydrogen, carbon dioxide and a small amount of carbon monoxide.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

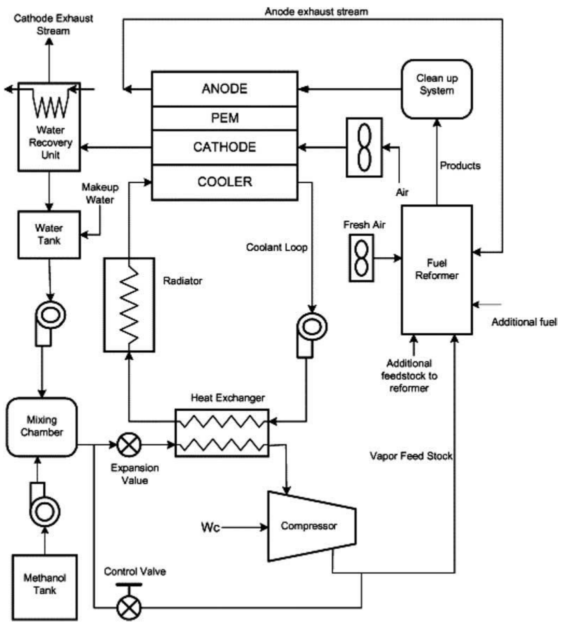


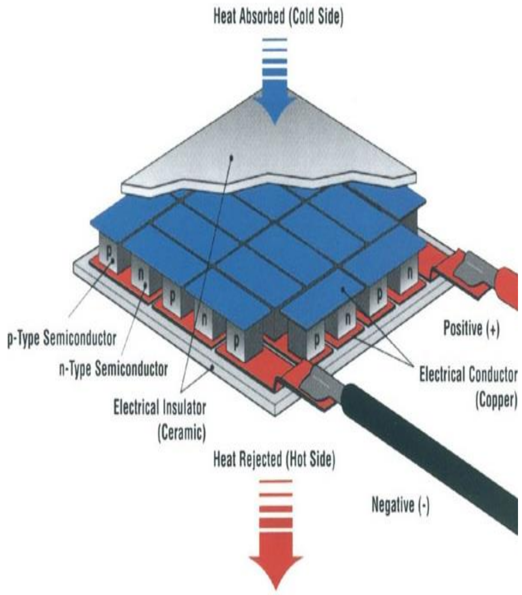

Fig.1.3.2: Schematic of a typical PEM fuel cell power plant incorporating the energy recovery system [Ref. by Amir Faghri, Zhen Guo]

Additional thermal energy may be needed for the reforming reaction. This heat is usually provided through a burner in the reformer that burns the hydrogen remaining in the anode exhaust stream. The hydrogen-rich gas generally requires cooling and clean up before it arrives at the stack.[9-12]

Thermal management issues are closely related to the fuel cell operating temperature. For example, low temperature fuel cells (e.g., PEMFC and DMFC) usual operate below 100 _C, whereas solid oxide fuel cells (SOFC) operate near 1000 _C. Therefore, heat transfer problems could be dramatically different in low temperature fuel cells and SOFCs.

***Thermoelectric Generator:***

The thermoelectric generators recover useful energy by the function of thermoelectric modules which can convert waste heat energy into electricity from automotive exhaust or any other sources. In the real activity, the electrical associated thermoelectric modules are worked under temperature befuddle conditions and after that the issue of diminished power yield causes because of the inhomogeneous temperature angle dispersion on warmth exchanger surface. The thermoelectric generator (TEG) is a device for directly converting thermal energy into electrical energy based on the See beck effect and it has presented urgent potential in the case of waste heat recovery. The TEGs have many advantages such as no moving mechanical parts, long-lived, quiet, environmentally friendly and requiring little maintenance. When a p-type element electrically connects to the n-type element, the mobile holes in the p-type element “see” the mobile electrons in the n-type element and migrate just to the other side of the junction.




When one electrically connects a p-type element to the n-type element, the mobile holes in the p-type element “see” the mobile electrons in the n-type element and migrate just to the other side of the junction. For every hole that migrates into the n-type element, an electron from the n-type element migrates into the p-type element. Soon, each hole and electron that “switch sides” will be in equilibrium and act like a barrier, preventing more electrons or holes from migrating. This is called the depletion zone.

### *1.4 Low temperature PEM fuel cells*

Proton exchange membrane fuel cells (PEMFCs) work at a low temperature, having the advantage of a quick startup. Use of a thin solid electrolyte facilitates the compact PEM fuel cell design. Either hydrogen or methanol can be used as fuel. If hydrogen is used, over-potential occurs mainly at the cathode. In contrast, for fuel cells using methanol, activation over-potential at both electrodes is important. While crossover does occur with hydrogen fueled fuel cells, the problem of fuel crossover is much worse with methanol. Methanol crossover is the process by which methanol diffuses from the anode through the electrolyte to the cathode, where it will react directly with the oxygen, producing no current from the cell. Furthermore, methanol has a poisoning effect on the cathode catalyst that will reduce the performance of the cell. Therefore, the performance of direct methanol fuel cells is limited by the crossover of methanol and catalytic inefficiency.[17]

Fig.1.4.1 shows the basic structure of a PEMFC, which can be subdivided into three parts: the membrane electrode assemblies (MEAs), the gas diffusion layers (GDLs) and bipolar plates. The MEA is the key component of PEMFCs. It is composed of a proton exchange membrane sandwiched between two fuel cell electrodes; the anode, where hydrogen is oxidized and the cathode, where oxygen from air is reduced.

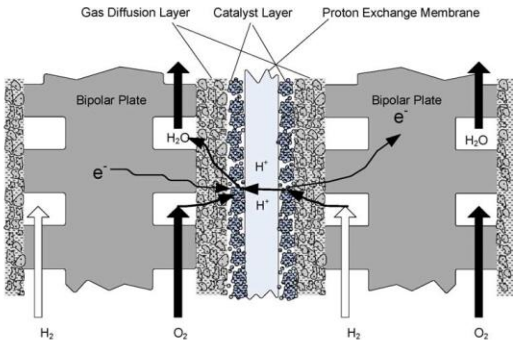


Fig.1.4.1: Basic construction of a typical PEM fuel cell stack.[ Ref. by Zhen Guo]

A gas diffusion layer is formed from a porous material, which must have high electric conductivity, high gas permeability, high surface area and good water management characteristics.

One side of the bipolar plate is next to the cathode of a cell, while the other side is next to the anode of the neighboring cell. The fuel cell stack consists of repeated interleaved structure of MEAs, GDLs and bipolar plates. All these components are clamped together with significant force to reduce electric contact resistance[16].

### *1.5 Heat transfer issues related to PEM fuel cell stacks*

A typical hydrogen PEMFC has relatively high power generation efficiency, at approximately 50%. This means\ the remaining 50% is waste heat. The heat must be discharged efficiently from the fuel cell to protect the proton exchange membrane. Cooling methods are determined greatly by the size of the fuel cell . Some commonly used cooling methods are summarized as follows:

Cooling with cathode wind current. For a little power device, the cathode can work in one of two modes: airbreathing (normal convection) or constrained wind stream (constrained convection). Common convection is the most straightforward approach to cool the cell and vanish water at the cathode. This is finished with a genuinely open structure at the cathode sides, which will build the volume of the stack. Constrained convection wind current is another advantageous method to bring the waste warmth out of the stack. This will bring about an increasingly minimized stack structure and increment the cooling ability. Nonetheless, exceptionally high cathode wind current speed or an extremely huge gas channel is vital for expulsion of waste warmth. At the point when the intensity of the power device is higher than a couple of hundreds watts, an increasingly successful cooling approach must be applied. Fundamental development of an average PEM power module stack.

Cooling with separate air flow. Although simply increasing reactant air flow can remove more heat, too much reactant air may dry out the proton exchange membrane. In such cases, fuel cells will generally need a separate reactant air supply and cooling system. A PEM fuel cell structure with separate cooling plates, through which air is blown. The advantage of this structure is that it can extract more heat from the stack without affecting air flow.

Cooling with warmth spreaders. Clearly warmth can be moved all the more effectively outside the stack. Warmth spreaders can be utilized to ship warmth out of the stack through conduction, at that point to scatter the warmth to encompassing air through characteristic or constrained convection. To include as meager additional weight and volume as conceivable to the stack, superior warmth spreaders must be utilized.

Water cooling. For hydrogen PEMFCs larger than 10 kW, it is generally necessary to use water cooling. Units below 2 kW can be air cooled, and cells between 2 kW and 10 kW require judicious decision making as to use of water or air cooling. Water cooling requires a more complex design: the temperature and pressure of the cooling water must be monitored and the flow of cooling water must be supplied via an oil-free water pump. Stack cooling in DMFCs is relatively simpler, since increasing circulation of dilute methanol solution at the anode could remove more waste heat from the stack.

Cooling with radiator fluid/coolant. The water cooling of PEM power devices offers ascend to issues related with water the board, for example, averting the item water from solidifying, and quickly dissolving any solidified water during beginning up at whatever point the energy component framework is worked in sub-solidifying conditions. A liquid catalyst coolant is substituted for ordinary water in the cooling framework for these circumstances.

## 2. LITERATURE REVIEW

Amir Faghri,Zhen Guo(2005): Challenges and opportunities of thermal management issues related to fuel cell technology and modelling resulted The loss due to contact resistance is a significant factor in fuel cell operation, and future fuel cell models should address the numerical modeling of contact resistance loss. A. Fly*, R.H. Thring(2016): Work on A comparison of evaporative and liquid cooling methods for fuel cell vehicles resulted the primary reason for the improvement seen by the evaporative cooling design is due to phase change within the radiator tubes, although for these benefits to be achieved a high liquid water separation efficiency is required. Hamideh Vaghari (2016) : Work on recent advance in application of chitosan in fuel cell who concluded improve the properties of chemical membrane such as sulfonation , phosphorylation , quaternization and formation of chitosan composite. Hao Ren (2017) : Work on effect of temperature on a miniaturized microbial fuel cell resulted As temperature increases then increases current density and then decreases. Liren Yang, Amey Karnik, Benjamin Pence(2017): Work on Liren Yang, Amey Karnik, Benjamin Pence resulted Thermal management is crucial for safe and efficient operation of fuel cells. Godwin E. Oyiwona (2018) : Work on electricity generation potential of wastewater resulted efficient electricity generation. Michael Nöst, Christian Doppler, Manfred Klell and Alexander Trattner(2018) : Work on Thermal Management of PEM Fuel Cells in Electric Vehicles who resulted High power requirements of PEMFC stacks while limited space at automotive applications are the significant challenges for a cooling system for FCEVs. Liquid cooling has been widely and successfully applied in automotive PEMFC stacks. Godwin E. Oyiwona1, James C. Ogbonna(2018): Work on Electricity generation potential of poultry droppings wastewater in microbial fuel cell using rice husk charcoal electrodes.

## 3.CONCLUSIONS/DISCUSSION

Hydrogen fuel cells are a promising alternative to current automobile fuels. They essentially combine the energy density and the convenience of liquid fuels with the clean and efficient operation of electric vehicles. Fuel cell technology promises to be a highly efficient and environmental-friendly power source with broad applications, including transportation and both portable and stationary power generation. Although tremendous progress in fuel cell stack and system development has been made in past decades, fuel cells are still relatively far from being fully commercialized. Numerous technical challenges remain, such as performance, cost, system issues, and choice of fuel. Thermal management plays an important role in fuel cell design and optimization from single cells to the system level. Manufacturing and operational costs can be reduced by optimizing the efficiency of fuel cells through detailed analysis of heat and mass transport phenomena taking place within the stack and system. This paper has revealed challenges and opportunities of thermal management issues related to low temperature fuel cells and high temperature fuel cells. Thermal management is closely related to water management in PEM fuel cells, where water is used for both humidification of reactant gases and cooling purposes. Thermal management is also a key tool for system energy balance design. This is particularly true for fuel cell systems that include a reformer, which increases the system complexity dramatically. Heat transfer in auxiliary components such as heat exchangers, blowers, burners, etc., also needs careful consideration and implementation.

## REFERENCES

[1] Berenjian A, Chan N, Jafarizadeh Malmiri H: Volatile organic compounds removal methods: A review. Am J Biochem Biotechnol 2012, 8:220–229.-Springer
[2] Xianguo L: Principles of Fuel Cells. New York London: Taylor and Francis group; 1962. - Sciencedirect
[3] R.K. Ahluwalia, E.D. Doss, R. Kumar, Performance of high-temperature polymer electrolyte fuel cell systems, J.Power Sources 117 (2003) 45–60. - Sciencedirect
[4] Y. Cao, Z. Guo, Performance evaluation of an energy recovery system for fuel reforming of PEM fuel cell power plants, J. Power Sources 109 (2002) 287–293. -Elesevier
[5] Fronk MH, Wetter DL, Masten DA, Bosco A. Pem fuel cell system solutions for transportation. SAE Tech Pap 2000. 2000e01e0373, 2011-32-0644. .-Springer
[6] Adams JA, Chul Yang W, Oglesby KA, Osborne KD. The development of ford's p2000 fuel cell vehicle. SAE Tech Pap 2000. 2000e01e1061, 2011-32-0644-Elsevier.
[7] Rogg S, H€oglinger M, Zwittig E, Pfender C, Kaiser W,Heckenberger T. Cooling modules for vehicles with a fuel cell drive. Fuel Cells 2003;3:153e8. -Springer
[8] Zhang G, Kandlikar SG. A critical review of cooling techniques in proton exchange membrane fuel cell stacks. Int J Hydrogen Energy 2012;37:2412e29. -Springer
[9] M. Iwata, T. Hikosaka, M. Morita, T. Iwanari, K. Ito, K. Onda, Y. Esaki, Y. Sakaki, S. Nagata, Performance analysis of planar-type unit SOFC considering current and temperature.-Springer
[10] C. Belta and L. Habets. Controlling a class of nonlinear systems on rectangles. IEEE Trans. Autom. Control, 51(11):1749–1759, 2006. -Springer
[11] S. Coogan and M. Arcak. Efficient finite abstraction of mixed monotone systems. In Proc. of HSCC, pages 58–67. ACM, 2015.
[12] Noreikat KE, MTZ Wissen 11. Brennstoffzelle, Antriebsstrang und Infrastruktur, Apr 2013.-Springer
[13] N. Henao, S. Kelouwani, K. Agbossou, and Y. Dub´e. Proton exchange membrane fuel cells cold startup global strategy for fuel cell plug-in hybrid electric vehicle. Journal of Power Sources, 220:31–41, 2012-Springer
[14] Y. Saygili, I. Eroglu, S. Kincal, Model based temperature controller development for water cooled pem fuel cell systems, Int J Hydrogen Energy 40 615e622-Springer
[15] APHA (1998) Standard methods for examination of water and wastewater, 20th edn. American Health Association, Washington, D.C. -Springer
[16] Ren H, Lee H-S, Chae J (2012) Miniaturizing microbial fuel cells for potential portable power sources: promises and challenges. Microfluid Nanofluid 13(3):353–381. doi:10.1007/s10404-012-0986-7-Sciencedirect
[17] Andrea Montecucco, Jonathan Siviter, et al., The effect of temperature mismatch on the thermoelectric generators electrically connected in seriesandparallel, Appl Energy 123 (2014) 47−54