

MODELING AND ANALYSIS OF COOLING SYSTEM FOR FUEL CELL

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering Degree in

Automobile Engineering

By

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DEPARTMENT OF AUTOMOBILE ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **GOWTHAM SRI RAM K** (Register No. **38860702**), **SRIRAM PRASATH S** (Register No. **38860016**) who carried out the project entitled "**MODELING AND ANALYSIS OF COOLING SYSTEM FOR FUEL CELL**" under my supervision from **October 2021 to MAY 2022**.

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DECLARATION

We, **GOWTHAM SRI RAM (Reg no. 38860702), SRIRAM PRASATH S (Reg no. 38860016)** hereby declare that the Project Report entitled “**MODELING AND ANALYSIS OF COOLING SYSTEM FOR FUEL CELL**” done by us under guidance of **Dr. DILLIP KUMAR SAHOO, M.E. Ph.D.** is submitted in partial fulfillment of the requirements for the award of **Bachelor of Engineering** degree In **Automobile**.

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ABSTRACT

Low start-up, high power density, high efficiency, portability, and long-range applications are just a few of the benefits of the proton exchange membrane (PEM) fuel cell. More than half of the chemical energy of hydrogen is converted to heat during the generation of electricity in a polymer membrane fuel cell. As a result, the temperature of the cell rises. The cooling channel design and the coolant used have an impact on cell cooling. A cooling channel was built within the fuel cell in this study to examine the influence of cooling on fuel cell performance. DI100 (100 percent Deionized water), PG10 (90 percent DI water + 10% polypropylene Glycol), PG20 (80 percent DI Water + 20% Polypropylene Glycol), and PG30 (70 percent DI Water + 30% Polypropylene Glycol) are the four coolant combinations used to test fuel cell performance. To measure efficiency, a computational fluid dynamics model based on the finite volume technique was used. The performance of the system was assessed based on the temperature, operational parameters, coolant, and cooling channel shape. The results of Relative Humidity, Membrane water content, Temperature, Enthalpy, and Internal energy are described in this study, which considers a single fuel cell and a stack.

Keywords: ***Modelling, Fuel cell stack, Analysis, Cooling system***

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LIST OF ABBREVIATIONS

FC	FUEL CELL
PEM	POLYMER ELECTROLYTE MEMBRANE
AFC	ALKALINE FUEL CELL
PAFC	PHOSPHORIC ACID FUEL CELL
MCFC	MOLTEN CARBONATE FUEL CELL
SOFC	SOLID OXIDE FUEL CELL
CFD	COMPUTATIONAL FLUID DYNAMICS
CO	CARBON MONOXIDE
FCV	FUEL CELL VEHICLES
BoP	BALANCE OF PLANT
DI	DEIONIZED
PG	POLYPROPYLENE GLYCOL
STEP	STANDARD FOR THE EXCHANGE OF PRODUCT DATA
CAD	COMPUTER-AIDED DESIGN
K	KELVIN
EV	ELECTRICAL VEHICLE

CHAPTER 1

INTRODUCTION

1.1 FUEL CELL

1.1.1 Overview

A fuel cell is an electro chemical cell that converts the chemical energy of a fuel (usually hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. With the exception of flow batteries, fuel cells differ from most batteries in that they require a continuous supply of fuel and oxygen (usually from air) to keep the chemical reaction going, whereas chemical energy in a battery is usually derived from metals and their ions or oxides that are already present in the battery. Fuel cells can generate electricity indefinitely as long as fuel and oxygen are available.

In 1838, Sir William Grove invented the first fuel cells. The first commercial use of fuel cells happened more than a century after Francis Thomas Bacon's development of the hydrogen–oxygen fuel cell in 1932. NASA has used the alkaline fuel cell, sometimes known as the Bacon fuel cell after its inventor, to power satellites and space shuttles since the mid-1960s. Since then, fuel cells have been used in a number of additional applications. Fuel cells are used for primary and backup power in commercial, industrial, and residential constructions, as well as in remote or inaccessible locations. They are used to power fuel cell vehicles such as forklifts, automobiles, buses, trains, boats, motorcycles, and submarines.

There are many different types of fuel cells, but they always contain an anode, a cathode, and an electrolyte that allows ions, most often positively charged hydrogen ions, to move between the two sides of the fuel cell (protons). An anode catalyst initiates oxidation processes in the fuel, resulting in the production of ions (usually positively charged hydrogen ions) and electrons. The ions are transported from the anode to the cathode by the electrolyte. At the same time,

electrons pass from the anode to the cathode through an external circuit, giving direct current power. At the cathode, another catalyst initiates a reaction between ions, electrons, and oxygen, resulting in the creation of water and maybe other chemicals. The kind of electrolyte used in fuel cells is classified, as is the starting time, which varies from one second for proton-exchange membrane fuel cells (PEMFC) to ten minutes for solid oxide fuel cells (SOFC). Flow batteries are a similar technology that allows the fuel to be replenished by recharging. Because individual fuel cells have low electrical potentials (less than 0.7 volts), they must be "stacked," or linked in series, to create enough voltage to meet the demands of an application. In addition to electricity, fuel cells produce water, heat, and, depending on the fuel source, very small amounts of nitrogen dioxide and other pollutants.

Fuel cells come in a wide range of sizes and forms, but they all work in the same manner. The anode, electrolyte, and cathode are the three parts that are close together. Two chemical reactions occur at the intersections of the three segments. When fuel is burned, water or carbon dioxide is generated, and an electric current is created, which may be used to power electrical equipment, also known as the load. At the anode, a catalyst oxidizes the fuel, which is usually hydrogen, producing a positively charged ion and a negatively charged electron. The electrolyte is a substance that allows ions but not electrons to pass through it. The released electrons travelling over a wire form the electric current. The electrolyte transports ions from the anode to the cathode. The ions and electrons are reunited at the cathode, where they combine with a third molecule, usually oxygen, to form water or carbon dioxide.

1.1.2 Design Aspects

- The electrolyte is a substance made up of a number of elements such as potassium hydroxide, salt carbonates, and phosphoric acid that determines the kind of fuel cell.
- The kind of gasoline that was used. The most prevalent fuel is hydrogen.
- The anode catalyst, which is usually fine platinum powder, breaks down the fuel into electrons and ions.
- Ions are transformed into waste compounds, the most common of which is water,

by the cathode catalyst, which is commonly nickel.

- Gas diffusion layers that are resistant to oxidation.

A typical fuel cell produces a voltage of 0.6 to 0.7 V at full rated load. Voltage reduces when current rises due to a variety of factors.

- Activation decline
- Ohmic deficiency (voltage drop due to resistance of the cell components and interconnections)
- Lack of public transit (depletion of reactants at catalyst sites under high loads, causing rapid loss of voltage).

To provide the required amount of energy, the fuel cells can be linked in series to create a higher voltage and in parallel to deliver a higher current. A fuel cell stack is an example of this sort of construction. The cell surface area can also be increased to provide for a higher current from each cell.

1.2 WORKING OF FUEL CELL

Unit cells make up the core of a fuel cell. These devices convert a fuel's chemical energy into electrical energy electro chemically. An electrolyte layer in contact with an anode and a cathode on either side is the basic physical structure, or building block, of a fuel cell. Figure 1.2 depicts a unit cell with reactant/product gases and ion conduction flow directions through the cell in schematic form. Fuel is continually delivered to the anode (negative electrode) and an oxidant (typically oxygen from the air) is continuously fed to the cathode in a conventional fuel cell (positive electrode). Electrochemical reactions occur at the electrodes to generate an electric current that flows through the electrolyte while producing a complementary electric current that works on the load. A fuel cell is comparable to a traditional battery in many aspects, but it varies in others. The battery is an energy storage device that stores all of the available energy within the battery (at least the reductant). When the chemical reactants in the battery are depleted, the battery will stop producing electrical energy (i.e., discharged). A fuel cell, on the other hand, is an energy conversion device that

is continually supplied with fuel and oxidant. In theory, the fuel cell can generate electricity for as long as fuel is available. The choice of electrolyte and fuel determines the electrode reactions and the type of ions that carry the current across the electrolyte, which in turn determines the electrode reactions and the type of ions that carry the current across the electrolyte.

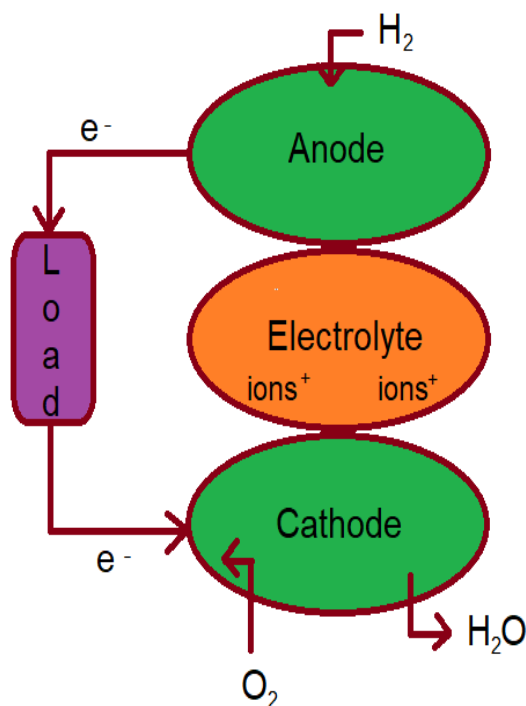


Fig 1.2 : Working Principle of Fuel Cell

Any chemically oxidizable substance that can be continuously supplied (as a fluid) can theoretically be burned galvanically as fuel at a fuel cell's anode. Similarly, the oxidant might be any fluid that can be rapidly reduced. Despite the fact that using common fuels directly in fuel cells would be ideal, most fuel cells in development today use gaseous hydrogen or a synthetic gas rich in hydrogen as a fuel. For anode processes, hydrogen has a high reactivity and may be generated chemically or electro chemically from a range of fossil and renewable sources. For similar practical reasons, gaseous oxygen, which is easily obtained from air, is the most common oxidant. Both hydrogen and oxygen may be kept in cryogenic form for space uses, whereas the reaction result is merely water.

1.2.1 Critical Function Of Cell Components

The three-phase interface is an important part of practically every unit cell. These relatively small zones, in which the true electro chemical reactions take place, may be detected where either electrode hits the electrolyte. For a site or region to be termed active, it must be exposed to the reactant, be in electrical contact with the electrode, be in ionic contact with the electrolyte, and contain enough electro catalyst to keep the reaction going at the proper rate. The density of these zones and the kind of their interfaces affect the electrochemical performance of both liquid and solid electrolyte fuel cells.

The reactant gases diffuse via a thin electrolyte film that wets portions of the porous electrode and react electrochemically on their corresponding electrode surface in liquid electrolyte fuel cells. If there is too much electrolyte in the porous electrode, it may "flood," preventing gaseous species from the electrolyte phase from reaching the reaction sites. As a result, the porous electrode's electro chemical performance deteriorates. As a result, the porous electrode structure must maintain a careful balance between the electrode, electrolyte, and gaseous phases. Engineering a high number of catalyst sites into the interface of solid electrolyte fuel cells that are electrically and ionically coupled to the electrode and electrolyte, respectively, and that are efficiently exposed to the reactant gases is a difficulty. In most effective solid electrolyte fuel cells, a high-performance interface necessitates the employment of an electrode with mixed conductivity in the zone near the catalyst (i.e. it conducts both electrons and ions).

The unit cell performance of at least some fuel cell technologies has increased considerably during the last two decades. Improvements in the three-phase boundary, a reduction in the thickness of the electrolyte, and the development of new electrode and electrolyte materials have all contributed to the expansion of the temperature range over which the cells can function.

Each of the unit cell components serves a key purpose in addition to allowing electro chemical processes. As shown in Figure 1-2, the electrolyte not only carries dissolved reactants to the electrode, but also transfers ionic charge across the electrodes, completing the cell electric circuit. It also acts as a physical barrier, preventing direct mixing of the fuel and oxidant gas streams. Aside from providing a surface for electro chemical reactions, porous electrodes in fuel cells must also conduct electrons away from or into the three-phase interface once they are formed (so an electrode must be made of materials with good electrical conductivity), as well as collect current and connect to other cells or the load. Ensure that the reactant gases are dispersed evenly throughout the cell. To guarantee that reaction products are effectively guided away from the reaction zone and into the bulk gas phase As a result, most electrodes are porous and constructed of an electrically conductive substance. The electro-catalytic activity of the bulk electrode material is frequently adequate in high-temperature fuel cells. Despite the fact that a variety of fuel cell shapes have been investigated, the majority of fuel cells now under development are either planar (rectangular or circular) or tubular (single- or double-ended, cylindrical or flattened).

1.3 TYPES OF FUEL CELL

A number of distinct fuel cells are at various phases of development. The kind of electrolyte used in fuel cells is the most popular categorization, which comprises 1) polymer electrolyte fuel cells (PEFC), 2) alkaline fuel cells (AFC), 3) phosphoric acid fuel cells (PAFC), 4) molten carbonate fuel cells (MCFC), and 5) solid oxide fuel cells (SOFC). The operating temperature range of the fuel cell is mostly determined by the electrolyte used. The physicochemical and thermo mechanical qualities of materials used in fuel cell components are determined by the operating temperature and useful life of the cell (i.e., electrodes, electrolyte, interconnect, current collector, etc.). Because of their high vapour pressure and

quick deterioration at higher temperatures, aqueous electrolytes are confined to temperatures of around 200 °C or below. The degree of fuel processing that is required is also influenced by the operating temperature. Before entering a low-temperature fuel cell, all of the fuel must be converted to hydrogen. Furthermore, CO poisons the anode catalyst (often platinum) in low-temperature fuel cells. CO and even CH₄ can be internally transformed to hydrogen or electro chemically oxidised in high-temperature fuel cells.

1.3.1 Polymer Electrolyte Fuel Cell (PEMFC)

An ion exchange membrane (fluorinated sulfonic acid polymer or other similar polymer) that is an efficient proton conductor serves as the electrolyte in this fuel cell. Because water is the sole liquid in this fuel cell, corrosion issues are low. Carbon electrodes with platinum electrocatalyst are often utilised for both the anode and the cathode, with either carbon or metal interconnects. Because the membrane must be hydrated, water management in the membrane is crucial for optimal performance. The fuel cell must function in settings where the by-product water does not evaporate faster than it is generated. Because of the polymer's working temperature constraint, which is normally less than 100 °C, but more commonly around 60 to 80 °C. Due to water balance issues, an H₂-rich gas with little or no CO (a toxin at low temperatures) is employed. For both the anode and cathode, a higher catalyst loading than that utilised in PAFCs is required. Other fuels require extensive fuel processing since even tiny quantities of CO, sulphur species, and halogens can poison the anode.

PEFCs are being researched for a number of uses, including primary power for fuel cell cars (FCVS). Because of the significant interest in FCVS and hydrogen, PEFC investment has easily outpaced all other forms of fuel cells over the last decade. Although PEFC has seen substantial progress for fixed applications, many developers are now concentrating on automotive and portable applications.

ADVANTAGES - The PEFC contains a solid electrolyte that provides good gas crossover resistance. Because the PEFC operates at a low temperature, it can

start up quickly, and because there are no corrosive cell ingredients, it does not require the use of unusual materials that are necessary in other fuel cell types, both in stack building and in the BoP. PEFCs have been shown to be capable of high current densities of over 2 kW/l and 2 W/cm² in tests. The PEFC is particularly well suited to conditions in which pure hydrogen may be used as a source of energy.

DISADVANTAGES - Thermal management is problematic because to the low and limited working temperature range, especially at extremely high current densities, and it is difficult to utilise the rejected heat for cogeneration or bottoming cycles. Engineers must balance maintaining sufficient hydration of the electrolyte versus flooding the electrolyte, which is another key problem in PEFC design. Furthermore, PEFCs are highly susceptible to contamination by trace quantities of pollutants such as CO, sulphur species, and ammonia. Some of these drawbacks can be mitigated to some extent by decreasing operating current density and increasing electrode catalyst loading, although both raise the system's cost. The significant fuel processing required by hydrocarbon fuels has a detrimental influence on system size, complexity, efficiency (usually in the mid-thirties), and cost. Finally, the development of a hydrogen infrastructure is a hurdle to commercialization for hydrogen PEFC.

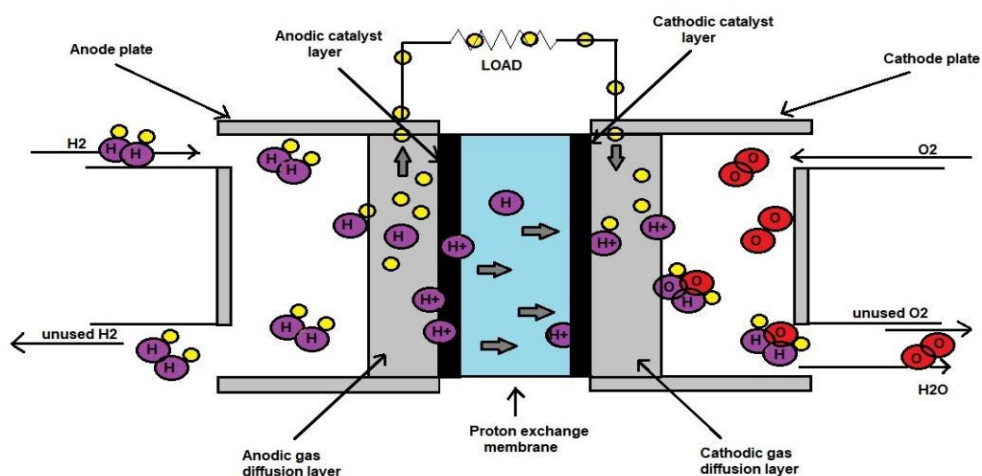


Fig 1.3.1 : construction of pemfc

1.3.2 Alkaline Fuel Cell (AFC)

The electrolyte of this fuel cell is either highly concentrated (85 wt%) KOH for high-temperature (250 °C) operation or less concentrated (35 to 50 wt%) KOH for lower-temperature (120 °C) operation. The electrolyte is held in place by a matrix (often asbestos), and a variety of electro-catalysts can be utilized (e.g., Ni, Ag, metal oxides, spinels, and noble metals). Except for hydrogen, the fuel source is restricted to non-reactive components. CO is poisonous, and when CO₂ reacts with KOH to generate K₂CO₃, the electrolyte changes. Even a modest amount of CO₂ in the air must be regarded as a possible toxin to the alkaline cell. Although some direct carbon fuel cells employ (different) alkaline electrolytes, hydrogen is generally regarded to be the primary fuel for AFC. Beginning in 1960, the AFC was one of the first modern fuel cells to be created. At the time, the application was to supply on-board electric power for the Apollo spacecraft. The AFC has had a lot of success in space applications, but its sensitivity to CO₂ has made it difficult to use on the ground.

ADVANTAGES - Due to its active O₂ electrode kinetics and flexibility to utilize a wide range of electro-catalysts, the AFC has good performance on hydrogen (H₂) and oxygen (O₂) when compared to other possible fuel cells.

DISADVANTAGES - The electrolyte's sensitivity to CO₂ necessitates the use of ultra pure H₂ as a fuel. As a result, using a reformer would necessitate a very efficient CO and CO₂ removal system. Furthermore, if the oxidant is ambient air, the CO₂ in the air must be eliminated. While this is not technically difficult, it has a major influence on the system's size and cost.

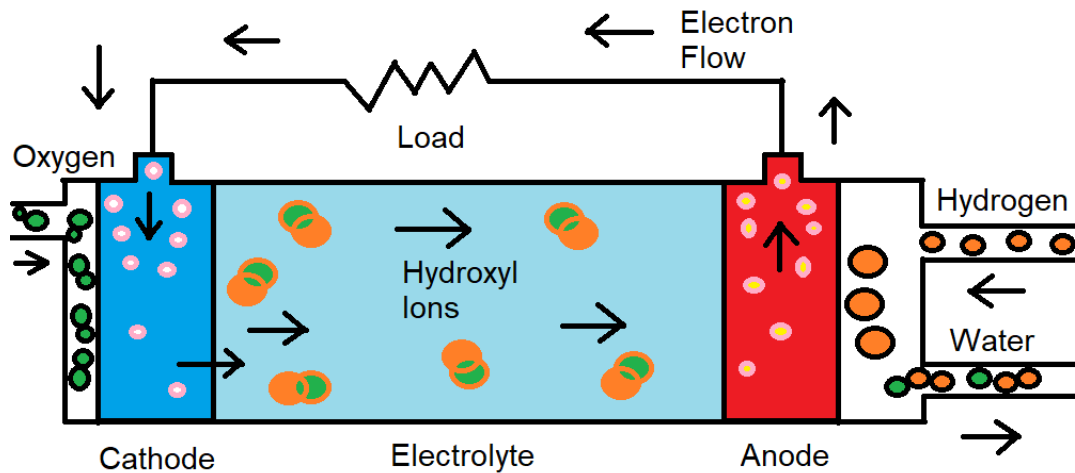


Fig 1.3.2 : Schematic of Alkaline Fuel Cell

1.3.3 Phosphoric Acid Fuel Cell (PAFC)

The electrolyte of this fuel cell, which runs at 150 to 220 °C, contains phosphoric acid that has been concentrated to 100%. Phosphoric acid is a weak ionic conductor at lower temperatures, and CO poisoning of the Pt electro-catalyst in the anode becomes severe. Because concentrated phosphoric acid has a high relative stability compared to other common acids, the PAFC may operate at the high acid temperature range (100 to 220 °C). Furthermore, because concentrated acid (100 %) reduces water vapour pressure, water management in the cell is simple. Silicon carbide is the most popular matrix for retaining acid, while Pt is employed as an electro-Catalyst in both the anode and cathode. PAFCS are primarily designed for fixed use. Hundreds of PAFC systems were manufactured, sold, and utilized in field experiments and demonstrations in both the United States and Japan. It's still one of the few commercially accessible fuel cell systems. In the last 10 years, PAFC development has halted in favour of PEFCs, which are regarded to offer higher cost potential. PAFC development, on the other hand, continues.

ADVANTAGES - PAFCS are less sensitive to CO than PEFCs and AFCs, with PAFCS tolerating roughly 1% CO as a diluent. At least in the BoP components,

the working temperature is still low enough to allow the use of standard building materials. The operating temperature also allows for a lot of design flexibility when it comes to thermal management. System efficiencies of 37 to 42 percent (based on LHV of natural gas fuel) have been demonstrated for PAFCS, which is greater than most PEFC systems (but lower than many SOFC and MCFC systems). Furthermore, waste heat from PAFC can be utilized in most commercial and industrial cogeneration applications, and a bottoming cycle may potentially be used.

DISADVANTAGES - The oxygen reduction on the cathode side is slower than in AFC, and thus necessitates the employment of a Platinum catalyst. PAFCS, while less complex than PEFCs, nevertheless need considerable fuel processing, which often includes a water gas shift reactor, in order to attain high performance. Finally, because phosphoric acid is very corrosive, it necessitates the use of costly materials in the stack (especially the graphite separator plates).

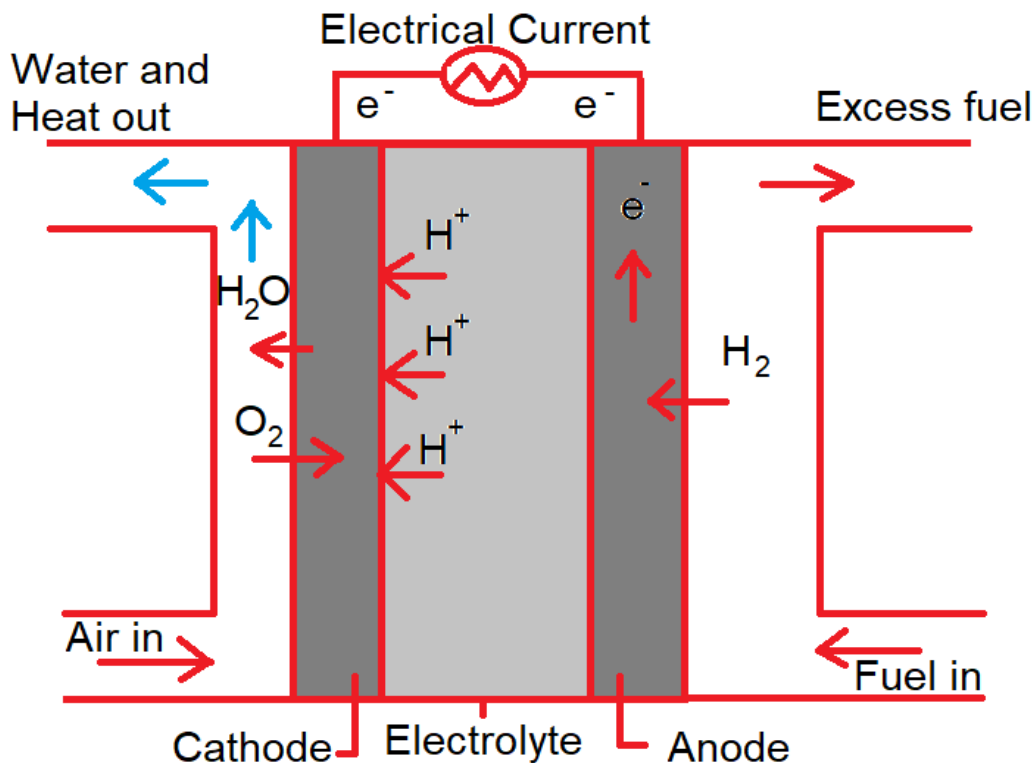


Fig 1.3.3 : Construction Of Phosphoric Acid Fuel Cell

1.3.4 Molten Carbonate Fuel Cell (MCFC)

The electrolyte in this fuel cell is typically a mixture of alkali carbonates that is held in a LiAlO_2 ceramic matrix. The alkali carbonates create a highly conductive molten salt at 600 to 700 degrees Celsius, with carbonate ions providing ionic conduction. Ni (anode) and nickel oxide (cathode) are sufficient to induce reaction at the high operating temperatures of MCFCS. Many common hydrocarbon fuels may be regenerated internally, and no noble metals are required for operation. Larger fixed and maritime applications have been the focus of MCFC development, where the MCFC'S comparatively enormous size and weight, as well as its delayed start-up time, are not a hindrance. MCFCS are being developed for use with a variety of fuels, both conventional and renewable. For DCFC, MCFC -like technology is also being studied. Following the PAFC, MCFCS have been extensively proven in stationary applications, with dozens of demonstration projects now underway or finished. Despite the fact that the number of MCFC developers and the amount of money invested have decreased since a decade ago, development and demonstrations have continued.

ADVANTAGES - The MCFC'S relatively high operating temperature (650 °C) offers a number of advantages: CO and certain hydrocarbons are both fuels for the MCFC because they are converted to hydrogen within the stack , simplifying the BoP and improving system efficiency to the high forties to low fifties; and both CO and certain hydrocarbons are fuel Furthermore, the high-temperature waste heat permits the employment of a bottoming cycle, increasing system efficiency to the high fifties and low sixties.

DISADVANTAGES - The highly corrosive and mobile electrolyte, which necessitates the use of nickel and high-grade stainless steel as cell hardware, is the key difficulty for MCFC developers (cheaper than graphite, but more expensive than ferritic steels). Material difficulties are exacerbated by greater temperatures, which have an influence on mechanical stability and stack life. Additionally, a supply of CO_2 (typically recycled from anode exhaust) is required

at the cathode to generate the carbonate ion, which represents extra BoP components. At realistic working voltages, high contact resistances and cathode resistance limit power densities to roughly 100 – 200 mW/cm².

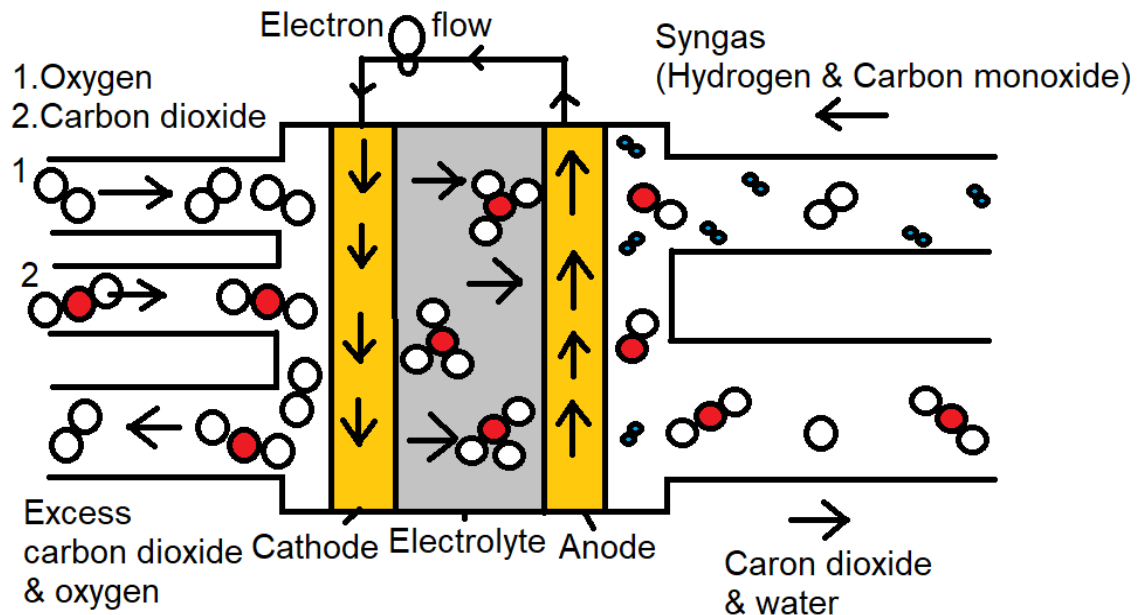


Fig 1.3.4 : Construction Of Molten Carbonate Fuel Cell

1.3.5 Solid Oxide Fuel Cell (SOFC)

The electrolyte in this fuel cell is commonly Y₂O₃-stabilized ZrO₂, which is a solid, nonporous metal oxide. Ionic conduction by oxygen ions takes place at 600-1000 °C in the cell. The anode is usually Co-ZrO₂ or Ni-ZrO₂ cermet, with a Sr-doped LaMnO₃ cathode. Due to the restricted conductivity of solid electrolytes, cell operation was once limited to roughly 1000 °C, but thin-electrolyte cells with better cathodes have allowed operating temperatures to be reduced to 650–850 °C. Some researchers are striving to decrease the operating temperatures of SOFCs even more. This has permitted the creation of small and high-performance SOFCs using relatively low-cost building materials during the last decade. The research and development of thin-electrolyte planar SOFCs has improved significantly thanks to concerted stack development

efforts, particularly through the U.S DOE'S SECA programme. SOFCS are currently being explored for a wide range of applications, including fixed power production, mobile power, auxiliary power for vehicles, and speciality applications, as a result of the performance advancements.

ADVANTAGES - The SOFC has been under continuous development for the longest time, beginning in the late 1950s, several years before the AFC. The cell may be cast in numerous forms, such as tubular, planar, or monolithic, due to the solid electrolyte. The unit cell's solid ceramic structure eliminates any potential corrosion issues. The solid electrolyte also enables for exact engineering of the three-phase boundary while also preventing electrolyte movement or flooding in the electrodes. The cell's kinetics are quite quick, and CO, like in the MCFC, is an immediately usable fuel. Unlike the MCFC, there is no necessity for CO₂ at the cathode. The materials utilized in SOFC are quite inexpensive. The ability of thin-electrolyte planar SOFC unit cells to reach power densities comparable to PEFC has been established. The high working temperature, like that of the MCFC, allows most of the waste heat to be used for cogeneration or bottoming cycles. Efficiencies ranging from roughly 40% (single cycle small systems) to over 50% (hybrid systems) have been proven, and 60% efficiency is possible, just as it is with MCFCS.

DISADVANTAGES - The SOFC'S high temperature has certain disadvantages. Thermal expansion incompatibilities exist between materials, making cell sealing challenging in flat plate arrangements. The high operating temperature imposes significant limitations on material choices and makes manufacturing procedures problematic. Metal stack components (such as interconnects in some systems) are prone to corrosion. These constraints restrict power density at the stack level (albeit it is substantially greater than in PAFC and MCFC), as well as thermal cycling and stack life (though the latter is better than for MCFC and PEFC).

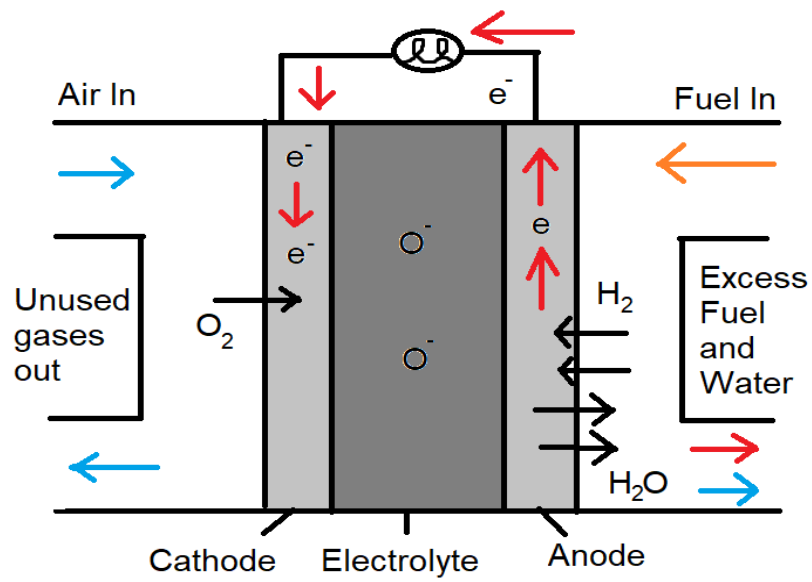


Fig 1.3.5 : Schematic Of Solid Oxide Fuel Cell

CHAPTER 2

LITERATURE SURVEY

- 1. S. O. Obayopo, "CFD modeling of cooling channel geometry of pem fuel cell forenhanced thermal performance," Nigerian Journal of Technology (NIJOTECH), Vol. 37, No. 1, January 2018, pp. 147 – 157**

The authors explain the numerical model they used to investigate the effects of cooling channel shape and temperature-dependent operational parameters on thermal management and overall performance of a PEM fuel cell system in this research. The evaluation is based on a finite volume technique and a computational fluid dynamics model. The performance of the system is represented as a function of system temperature, operational parameters, and cooling channel shape. The findings show that adding cooling channels into fuel cell structures increases PEM fuel cell system performance at higher operating temperatures, and that for the fuel cell model under consideration, there is an ideal cooling channel aspect ratio for best fuel cell performance. In addition, a mathematical optimization code was incorporated into the CFD code to optimise the parameters studied.

- 2. Afshari, Ebrahim, Nabi Jahantigh, and Masoud Ziaei-Rad. "Parametric study of the influence of cooling channel dimensions on PEM fuel cell thermal performance." Iranian Journal of Hydrogen & Fuel Cell 4.4 (2018): 265-274**

This study simulates cooling flow and heat transfer in cooling plates with parallel channels in a polymer membrane fuel cell, and three indexes are used to conduct a parametric study of the impact of cooling channel dimensions on fuel cell thermal performance: maximum surface temperature cooling, surface temperature uniformity, and pressure drop. The numerical results show that increasing channel depth decreases pressure drop and has a detrimental influence on temperature characteristics. As a result, in terms of constructional restrictions and mechanical

strength, utilising channels with a depth of 1 mm is recommended. When the channel width is extended, the maximum surface temperature of the cooling plate, the temperature uniformity index, and the pressure drop all decrease.

3. S.M. Rahgoshay, A.A. Ranjbar, A. Ramiar, E. Alizadeh, "Thermal investigation of a PEM fuel cell with cooling flow field," Energy, Volume 134, 1 September 2017, Pages 61-73

According to the authors of this study, simulating a PEMFC with a cooling flow field is done at the same time. Ansys Fluent software's conventional isothermal model (without cooling flow field) is compared to two types of cooling plate flow fields: serpentine and parallel. This comparison is made using physical elements such as pressure drop, lowest and maximum temperature gradients, Index of uniform temperature, and so on. Under identical operating conditions, the parallel and serpentine models had the same maximum temperature ratio, but the serpentine cooling flow field outperformed the parallel one by a few percent in terms of the index of uniform temperature. The results show that changing the heat transfer rate has a substantial influence on the performance of PEM fuel cells and PEMFCs with serpentine vs parallel cooling flow fields.

4. Q. Zhang, *et al.* Performance prediction of proton exchange membrane fuel cell engine thermal management system using 1D and 3D integrating numerical simulation Int. J. Hydrogen Energy, 43 (3) (2018), pp. 1736-1748

According to the authors of this study, the cooling system of a proton exchange membrane fuel cell (PEMFC) engine was studied using 1D and 3D collaborative modelling methodologies. To begin, the airside flow model is utilised to mimic the flow channel's resistance characteristics. A three-dimensional simulation model with twin fans and a radiator is developed to simulate the airflow distribution. A thermostat, water pump, fan, and radiator model are used to produce a one-dimensional simulation model of a 30 kW PEMFC engine cooling system. Second, the heat dissipation performance of the cooling system is determined using the connected simulation model. Finally, a simulation model is employed to model the

PEMFC system's thermal performance under extreme operating conditions. We can keep the stack's internal heat balances in check by monitoring pump flow and fan speed, resulting in efficient and consistent operation. Despite the fact that 1D thermal system simulation time is fast and can lead to quick heat transfer component matching, the data imply that 3D simulation can produce a more accurate fluid flow distribution.

5. Abdullah Alshorman, “Design and Investigation of Optimum Cooling System For Operative Performance Of PEM fuel cell” , International Journal of Emerging Trends in Engineering and Development , 2018-10.26808/rs.ed.i8v1.04

The authors of this research discussed the simulation study and proposed, developed, and tested a practical cooling system for PEMFC for maximum PEMFC performance and efficiency. The energy output of PEMFC is investigated using a variety of materials, geometries, working fluids, operating circumstances, and cooling fluid thermal characteristics. The findings show that greater flow rates and cooling fluid thermal characteristics, such as specific heat and convection heat transfer coefficient, as well as thermal emissivity and thermal conductivity, are associated to the greatest efficiency of the PEMFC cooling system. Furthermore, Argon as a cooling medium had an efficiency range of 60 to 80 percent, whereas water had a range of 40 to 55 percent and air had a range of 17 to 22 percent.

6. Um, S., et al., Computational fluid dynamics modeling of proton exchange membrane fuel cells, Journal of Electrochemical Society, 147, 2004, pp 4485-4493.

The authors explored the creation of a transient, multidimensional model to mimic proton exchange membrane fuel cells in this study. Electrochemical kinetics, current distribution, hydrodynamics, and multicomponent transport are all taken into consideration simultaneously in the model. Using a finite volume based computational fluid dynamics approach, a single set of conservation

equations valid for flow channels, gas diffusion electrodes, catalyst layers, and the membrane area is created and numerically solved. With good agreement, the numerical model is verified against published experimental data. The model is then used to investigate hydrogen dilution effects in the anode feed. Under hydrogen dilution circumstances, the anticipated polarisation curves are qualitatively consistent with recent studies published in the literature.

7. Yan, W-M., et al., Analysis of thermal and water management with temperature-dependent diffusion effects in the membrane of proton exchange membrane fuel cell, Journal of Power Sources, 129, 2004, pp 127137

In this study, the authors investigated the heat and water management in the membrane of proton exchange membrane fuel cells (PEMFC). To account for the coupling effects of mass diffusion and temperature gradient on the water distribution in the membrane, temperature-dependent diffusivity is utilised. Thermal and water transport equations with changeable boundary conditions are solved using the control volume finite difference method. According to projections, the impact of cathode temperature, T_c , on water concentration is substantial under fixed water concentration at the cathode side. T_c increases may lead to greater membrane dehydration. The impact of the operating temperature on the water distribution in the membrane in the water-flux state on the cathode side follows a similar pattern. The effects of anode temperature, T_a , on membrane water management are also investigated. T_a is discovered to have a significant influence on the water content of the membrane. Furthermore, a high current density might cause temperature distribution in the membrane to be non-uniform.

8. Satish C. Mohapatra., fuel cell and fuel cell coolant compositions, United States Patent, Patent No.: US 7,138,199 B2, 2006

The authors of this invention explored coolant compositions, specifically coolant compositions that may be used in fuel cells, as well as fuel cells that contain

such coolant compositions. This invention's coolant formulations or heat transfer fluids have low electrical conductivity and maintain it over long periods of time. These coolants, also known as heat transfer fluids, are made up of a base composition and an additive package that gives them the ability to maintain low electrical conductivity for long periods of time. The basic composition can be de-ionized water (DI water) alone or a combination of DI water plus a well-known freezing point depressant (e.g., propylene glycol). An organic corrosion inhibitor and a polymeric ion suppressor are included in the additive package. It's critical to employ both additive package components.

9. Cheng, C. H., et al., Design for geometric parameters of PEM fuel cell by integrating computational fluid dynamics code with optimization method, Journal of Power Sources, 165, 2007, pp803 – 813.

The authors of the current work used numerical modelling to optimise the geometric characteristics of proton exchange membrane (PEM) fuel cells. The method is created by combining a direct problem solution with an optimizer. As the direct problem solution, a commercial computational fluid dynamics code is utilised to model the three-dimensional mass, momentum, and species transport phenomena, as well as the electron- and proton-transfer process in a PEMFC. The simplified conjugate-gradient method (SCGM), on the other hand, is used to create the optimizer, which is then integrated with the direct problem solver to find the best geometric parameters, such as the gas channel width percentage, gas channel height, and gas diffusion layer thickness. The current method may be used to find the best collection of geometric parameters, and the search process is resilient, always leading to a unique final answer, independent of the original assumption.

10. Asghari S., et al., Design of thermal management subsystem for a 5kW polymer electrolyte membrane fuel cell system, J. Power Sources, 2011, 196(6): 3141

The performance and durability of PEM fuel cells are influenced by the high-efficiency heat management subsystem. The design of a thermal management subsystem for a 5kW PEM fuel cell system was examined in this work. The performance of the cooling flow field is investigated using a numerical model. The number of parallel channels in a parallel serpentine flow field is chosen as the flow field's design parameter, and the best value is found by balancing the least coolant pressure drop throughout the flow field with the highest temperature uniformity inside the bipolar plate requirements. Compromise between multiple parameters is often used to establish the best coolant flow rate. To verify the numerical simulation findings, test results of a 5-cell short stack are provided.

11. Kim, Y. B., Study on the effect of humidity and stoichiometry on the water saturation of PEM fuel cells, International Journal of Energy Research, 36,2012, pp 509-522.

The authors of this research looked at the impact of relative humidity (RH) and reactant stoichiometry on water saturation and local transport in proton exchange membrane fuel cells. A two-dimensional model was created to account for the influence of liquid water production on reactant transport. The findings show that the reactant RH and stoichiometry have a considerable impact on cell performance. A lower cathode RH preserves membrane hydration for higher cell performance at a constant anode RH of 100%. When the cathode RH is constant, a lower anode RH not only supplies more hydrogen to the catalyst layer to participate in the electrochemical process, but it also increases the difference in water concentrations between the anode and cathode.

12. Zhang G., et al., A critical review of cooling techniques in proton exchange membrane fuel cell stacks, Int. J. Hydrogen Energy, 2012, 37: 2412.

The authors of this study emphasised how effective cooling is crucial for the safe and efficient functioning of high-power proton exchange membrane fuel cell (PEMFC) stacks. The modest temperature differential between the stack and the

environment, as well as the restricted operational temperature range, provide considerable hurdles in cooling system design. This work examines cooling approaches presented in technical research papers and patents in order to support the development of effective cooling systems. The characteristics of heat generation and cooling needs in a PEMFC stack are described first.

13. Hashemi, F., et al., CFD Simulation of PEM Fuel Cell Performance: Effect of Straight and Serpentine Flow Fields, Mathematical and Computer Modelling, 55 (2012), 3-4, pp. 1540-1557.

The authors presented a complete non-isothermal, 3-dimensional model for investigating the performance of proton exchange membrane (PEM) fuel cells with straight and serpentine flow fields in this work. The model takes into account mass, heat, and energy flow in a fuel cell, as well as electrode kinetics and potential fields. For all fluxes in the cell, two flow patterns are considered: co-current and counter-current. The distributions of oxygen and hydrogen mass fractions, as well as current density and temperature, have been determined. Within the anode and cathode, the activation overpotential is constant. The results of the simulations indicated that the profiles differed from those predicted by simulations that assumed a constant activation overpotential.

14. Obayopo, S. O., et al., Three-dimensional optimization of a fuel gas channel of a PEM fuel cell for maximum current density, International Journal of Energy Research, 37, 2013, pp 228-241.

The authors of this paper explained how they created a three-dimensional numerical optimization of the influence of operating and design factors on PEM fuel cell performance. An anode flow channel, membrane electrode assembly, and cathode flow channel are all part of the model computational domain. Using a computational fluid dynamics code, the continuity, momentum, energy, and species conservation equations characterising the flow and species transport of the gas mixture in the connected gas channels and electrodes were numerically solved. The impacts of numerous essential factors on performance and species

distribution in a typical fuel cell system have been investigated, including channel geometries (width and depth), flow direction, and gas diffusion layer (GDL) porosity.

15. Awan, A., et al., Simulation of Proton Exchange Membrane Fuel Cell by using ANSYS Fluent, Materials Science and Engineering, 414 (2018), ID 012045

The authors use computational fluid dynamics simulations of PEMFCS in isothermal and non-isothermal conditions to explore fuel cell performance in the current work. Under non-isothermal circumstances, the effect of pressure and temperature on fuel cell performance is investigated. Under isothermal circumstances, the PEMFC is modelled at 323 K and 1 atm, whereas under non-isothermal conditions, the simulation is done at 353 K and 3 atm. The results reveal that when the operating pressure of a PEMFC increases, so does the current density, and vice versa as the operating temperature rises.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

The aim of the project is to investigate the influence of cooling system on fuel cell performance. The fuel cell performance is evaluated using four different types of coolant combinations namely 1) DI100 , 2) PG10 , 3) PG20 , 4) PG30 . Both single fuel cell and stack of fuel cells are used in this research to study the parameters and results are compared.

3.2 OBJECTIVE

The objective of this study is to analyze the performance of the fuel cell with a total of 6 cooling channels for each cell. And the cell behaviour is noted down . In order to find the better results different cooling compositions are induced in this study. The polymer electrolyte membrane fuel cell is used as a base model in this research. Fluent analysis is carried out with pem cell loader to simulate the actual fuel cell reaction with real-time parameters in ANSYS WORKBENCH to find out the cell behaviour for both single cell and stack of fuel cells. Parameters like temperature , Relative humidity , Membrane water content , Internal energy , Enthalpy , Peclet number etc are considered in this study.

CHAPTER 4

MATERIALS AND EXPERIMENTAL PROCESS

4.1 PEM FUEL CELL MATERIALS

4.1.1 Current collector

In any fuel cell current collector is a basic component . It provides conduction of electrons from the inside the electro chemical reaction to the exterior part without any reaction to the operation window . The most commonly used collectors in the market are made up of Aluminium(Al). Aluminium is used as both anode and cathode current collectors in this study.

4.1.2 Gas Diffusion Layer

The Gas Diffusion Layer is porous layer that ensures the reactants diffuse efficiently to the current collector. It also acts as a electric conductor, which transfers electrons between itself and current collector. They are generally made of porous carbon paper or carbon cloth that is approximately 100-300 micrometers thick. Carbon porous paper is considered for both anode and cathode gas diffusion layers in this study.

4.1.3 Catalyst water

Catalyst lowers the activation energy required , allowing the reaction the proceed more quickly or at a lower temperature. In fuel cell catalyst facilitates the reaction for both oxygen and hydrogen. It is generally made up of platinum or platinum powder deposited on thin carbon paper. Platinum is considered as a cathode and anode catalyst layer in this research.

4.1.4 Membrane

The role of membrane in fuel cell is to carry out hydrogen ions , protons from the anode to cathode without passing the electrons. The membrane decides the nature of

the fuel cell. For PEM fuel cell the membrane is made of Solid Polymer. So, in this study solid polymer membrane is considered.

4.2 COOLANT MATERIALS

Deionized (DI) water is the most often utilized coolant for fuel cell stack cooling. With an electrical resistance of 18 mega ohms, DI water has a high specific heat, thermal conductivity, and viscosity. As a result, staying cool by drinking DI water is a great idea. The resistivity of DI water decreases with time as ions from metals and other sources accumulate. In colder areas, DI water freezes at around 0 degrees Celsius, leaving it worthless. An anti-freezing chemical is used to strengthen the anti-freezing qualities. Glycol-based combinations are the most common anti-freezing agents. When mixed in the same proportion, Propylene glycol solutions have a higher viscosity and freezing point than ethylene glycol solutions, making them less thermally efficient, especially at lower temperatures. As a result, Propylene glycol is used as an anti-freezing agent in this investigation.

4.2.1 *Properties of Coolant*

Table 4.2.1 Basic properties of the propylene glycol and DI water base

Properties	DI water (100%)	Propylene Glycol (100%)
Freezing point (k)	273	213.15
Boiling point (k)	373.15	460.16
Density (g/cm ³)	1	1.036
Flashpoint (k)	not applicable	380.15
Specific heat (KJ/kg)	4.187	2.47
Specific gravity	1.000	1.074

4.2.2 Coolant Composition

This study's coolant is generated by combining propylene glycol (PG) with DI water in four different proportions: **DI100**, **PG10**, **PG20**, and **PG30**. **DI100** stands for **100 percent DI water**, **PG10** for **90 percent DI water + 10% propylene glycol**, **PG20** for **80 percent DI water + 20% propylene glycol**, and **PG30** for **70 percent DI water + 30% propylene glycol**. Table 4.2.2 shows the specifications of DI water and Propylene Glycol compositions used in this research. The primary goal of this research is to improve process parameters so that the PEM fuel cell system may achieve the best feasible implementation in terms of optimal current density (the objective function) in certain operating conditions. Furthermore, the optimization strategy should ensure that the optimal values of the components under consideration are constant.

Table 4.2.2 Properties of DI water and Propylene Glycol Compositions.

Properties	PG10	PG20	PG30
Freezing point(k)	270.15	1.008	373.15
Specific gravity	265.15	1.017	373.70
Boiling point (k)	287.15	1.026	375.37
Specific heat (KJ/kg)	4.103	4.021	3.915

4.3 METHODOLOGY

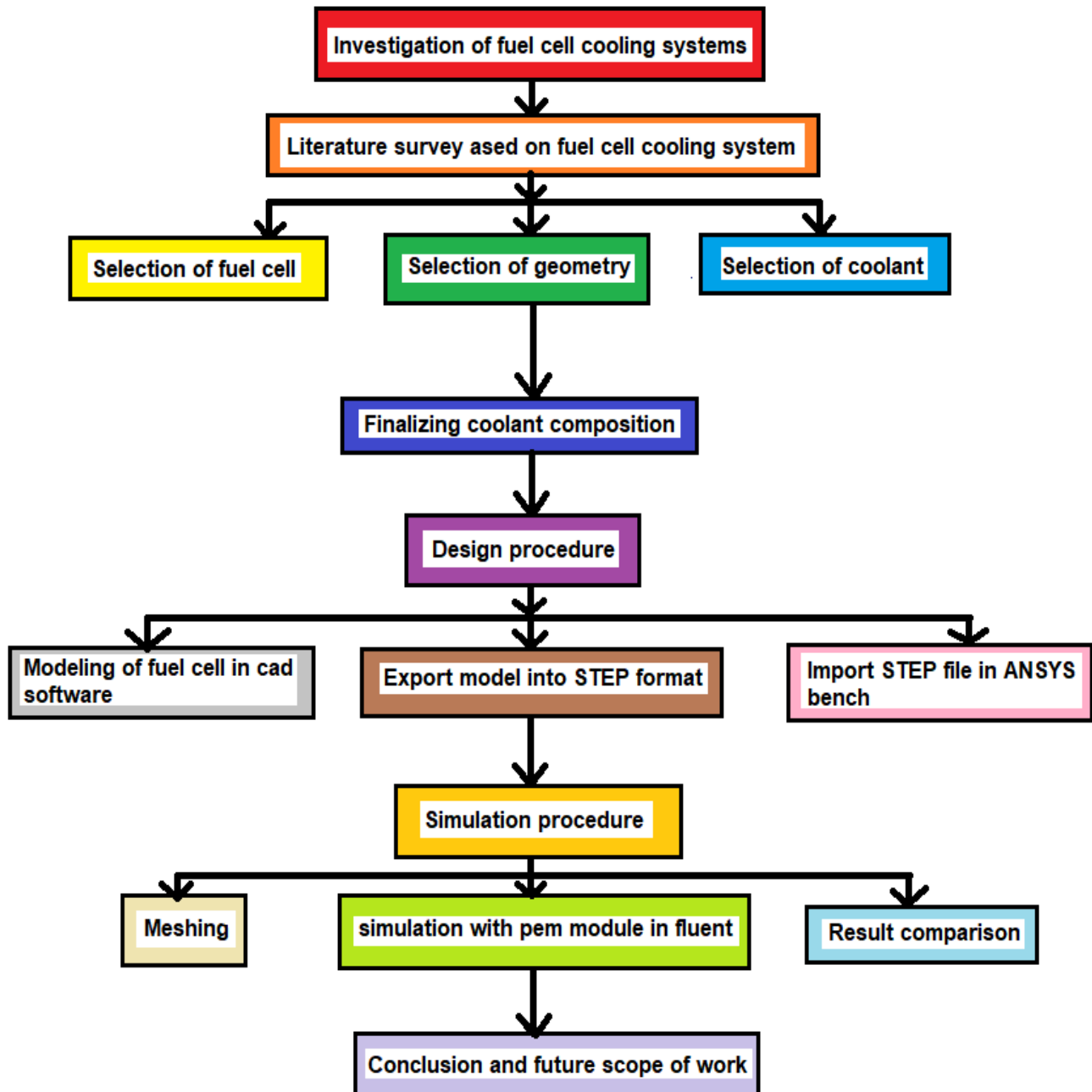


Fig 4.3 Simulation Methodology

4.4 SIMULATION PROCESS PARAMETERS

4.4.1 Fuel Cell Geometry

These are the design parameters for the research that need to be optimised. Three cooling channels transversely aligned at comparable distances are illustrated on each side (anode and cathode) of the bipolar plates of the PEM fuel cell. Table 4.4.1 includes the various physicochemical characteristics of the fuel cell system that were kept constant in this study, whereas Table 4.4.2 contains the model's properties.

Table 4.4.1 Parameters used in the present model

Geometry	Dimensions
Current collector	2mm * 2.5mm * 30mm
Gas diffusion layer	2mm * 0.12 mm * 30mm
Catalyst layer	2mm * 0.10mm * 30mm
Membrane	2mm * 0.20mm * 30mm
Channels	1mm * 1mm
Cooling channel	0.25mm * 0.20mm

Table 4.4.2 Properties used for the present fuel cell model

Descriptions	Single-cell	Stack
Cell operating temperature (k)	353.15	360
Inlet pressure air/fuel side	3/3	3/3
Operating Voltage (V)	0.65	1.3
The porosity of the gas diffusion layer	0.6	0.6
Absolute permeability of gd layer (m ²)	3e-12	3e-12
The porosity of the catalyst layer	0.2	0.2
Absolute permeability of catalyst layer (m ²)	2e-13	2e-13
Absolute permeability of membrane (m ²)	1e-18	1e-18
Coolant initial temperature(degree)	26.85	26.85
Coolant density (kg/m3)	998.2	998.2

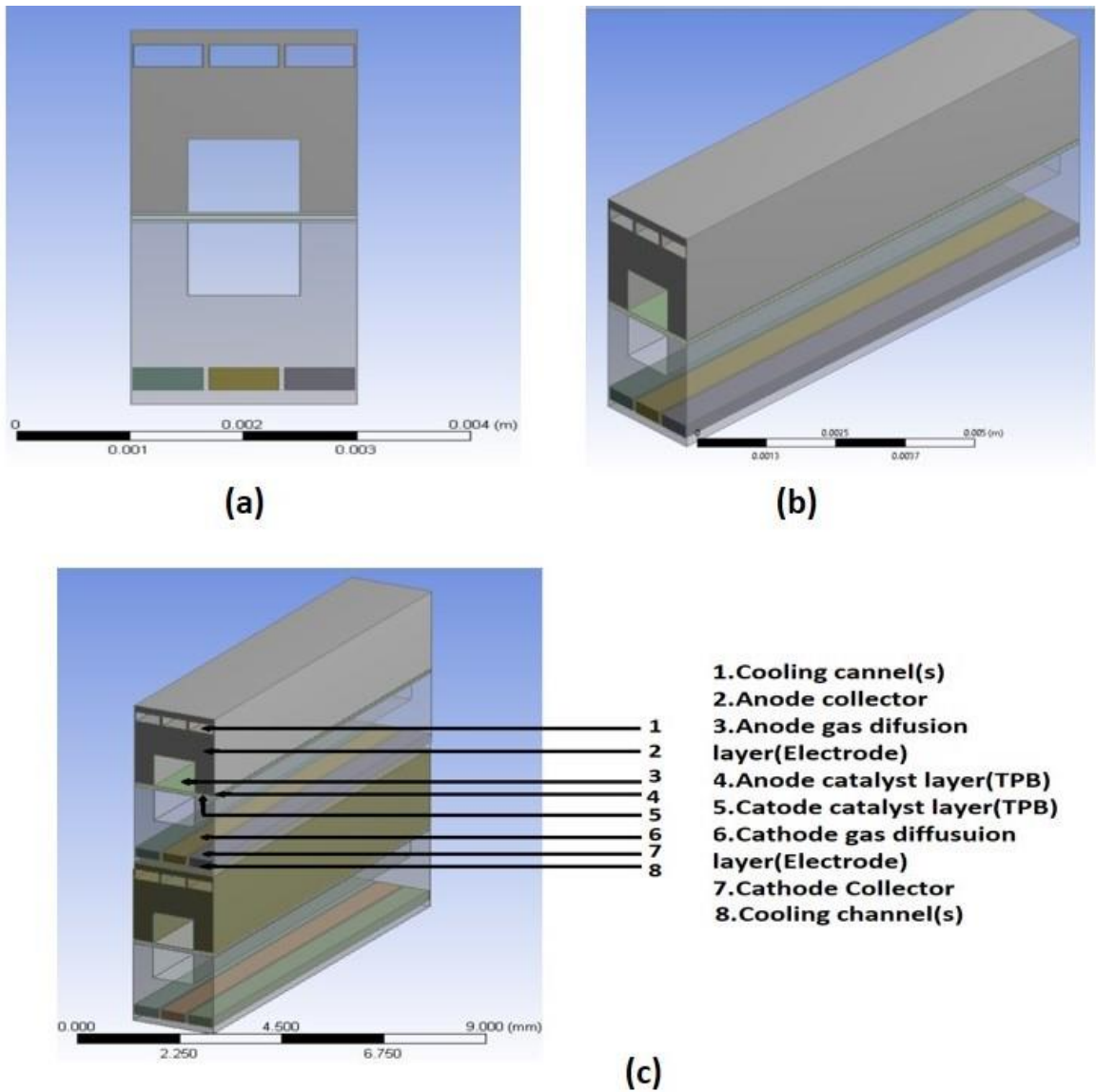


Fig 4.4.3 schematic and description of fuel cell

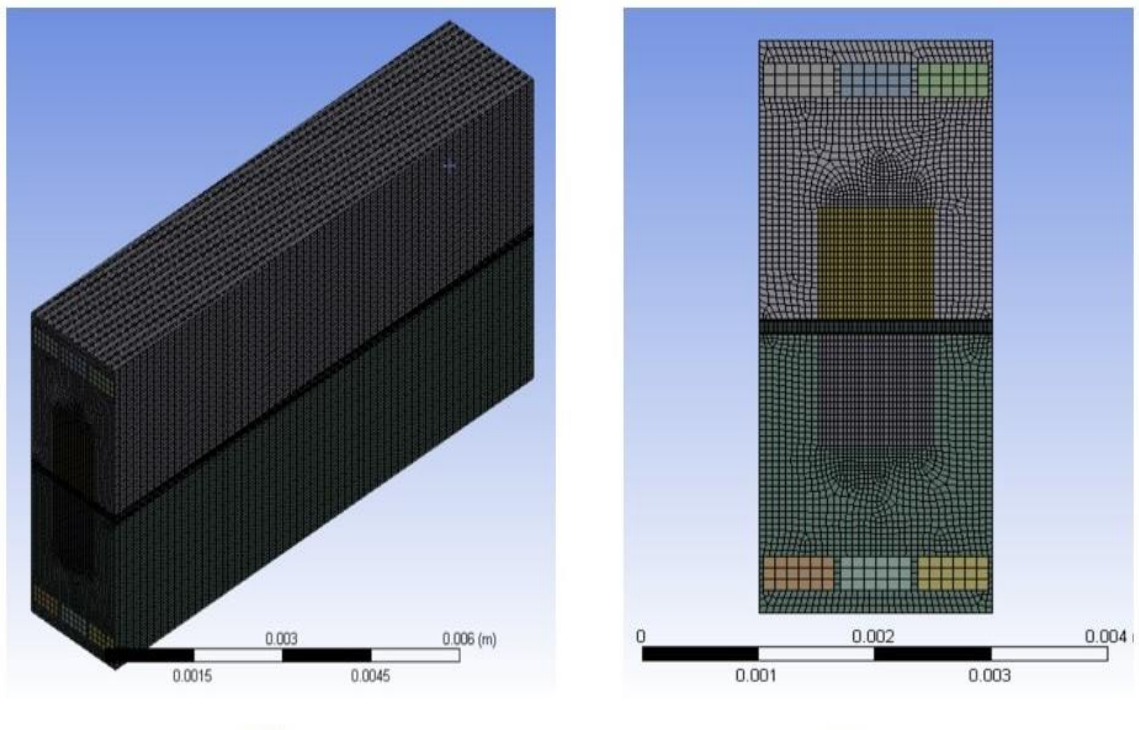
4.4.4 Meshing Details

Ansys Fluent's adjoint solver is utilized, which is a smart shape optimization tool that leverages CFD simulation results to determine optimum solutions based on given goals and then computes precisely how to adapt the design to achieve the ideal state. FLUENT software was used to perform numerical simulations of the flow field and heat transfer in the model. Finite element methods were used to solve the Continuity, Momentum, and Energy equations. For velocity and pressure

coupling, the SIMPLE algorithm is employed, and the second order upwind approach is evaluated for equation discretization. The mesh has a linear element order and a standard element size.

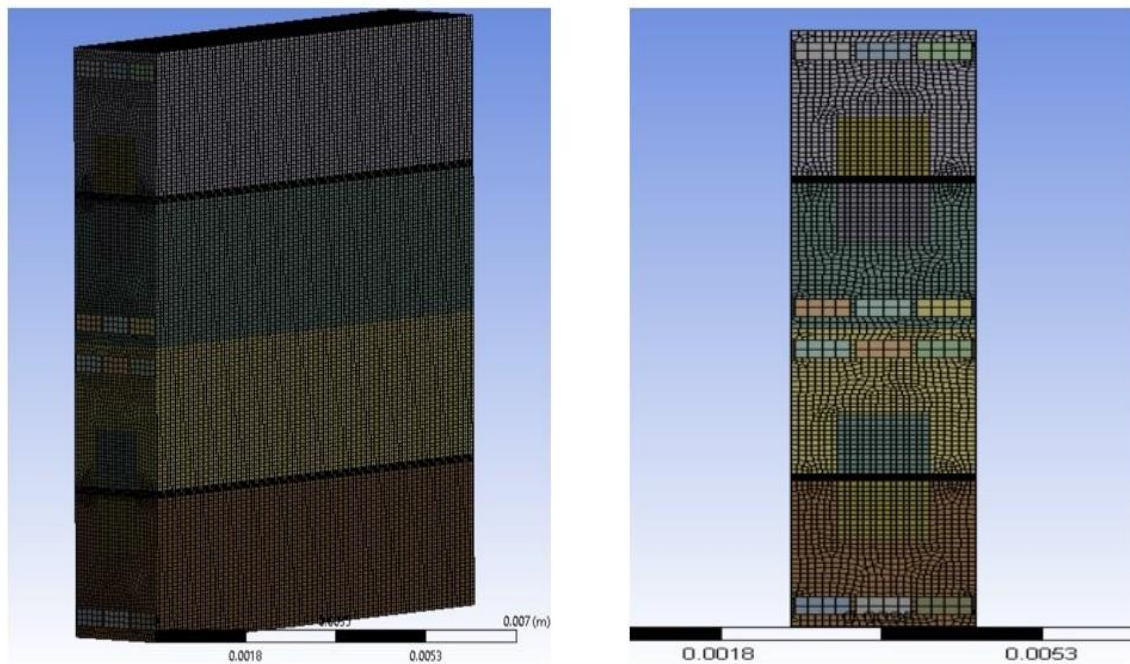
The adaptive sizing is enabled, and the mesh resolution is set to 7. Mesh defeaturing is enabled, with a standard size, a gradual transition, and a fine span angle centre, skewness of 0.95, and orthogonal value of >1 to eliminate meshing faults in the solution. There are 1015596 nodes and 948699 elements in a single cell shown in figure 4.4.5 , and 607676 nodes and 543712 elements in a stack shown in figure 4.4.6.

This model employs a series constructed stack. For additives with considerable cycle fatigue, structured (parametric) finite detail must be employed. With higher impact convergence and the use of dependent variables like brick with 8 (or) 20 nodes, controlling mesh transition in pressure gradient regions is possible. The use of brick factors is mono-atomic in the convergence of finite factors version. Brick detail may be generated via guide meshing, which comprises of dependent meshed parts and geometric transition management.



Statistics		
☐ Nodes		1015596
☐ Elements		948699

Fig 4.4.5 Meshed Model Of Single Fuel Cell



Statistics		
☐ Nodes		607676
☐ Elements		543712

Fig 4.4.6 Meshed Model of Stack

CHAPTER 5

RESULTS AND DISCUSSION

5.1 SIMULATION CHARACTERISTICS

The simulation results of both single cell and stack of fuel cell are carried out using Ansys fluent. An iso surface is created to view the indepth behaviour of the cells. Contours are created for each parameter to visualize the result. Parameters like Temperature , Relative Humidity , Membrane Water Content , Peclet Number , Enthalpy , Internal Energy , Reynolds Number and Current Density are analyzed for both single cell and stack. And the values are compared. The result shows that for single fuel cell 357k is the best working temperature obtained with PG30 coolant condition and for the stack 365k is the better temperature for efficient working obtained by PG20 condition. This shows the heat distribution In single cell and stack are different. These coolant conditions are considered the best due to the satisfactory outcomes in all the parameters are achieved. The highest temperature with DI100 condition is Obtained for both the single and stack of fuel cells and high amount of current density is also obtained. But the longevity of the cell is reduced due to less humidity in the cell. And when the temperature is low (below the working temperature) it leads to flooding in the cell, eventually the current density will be decreased. So the perfect working temperature should be maintained for more efficiency and longevity of the cell.

5.1.1 Iteration Graph For Single Cell And Stack

For both the single cell and stack of the fuel cell, the above graphs illustrate the change in energy, velocities, and H₂, O₂ lines. These are the iteration graphs of the fuel cell's single cell and stack. The calculations are performed using a conventional iteration range of 200 iterations.

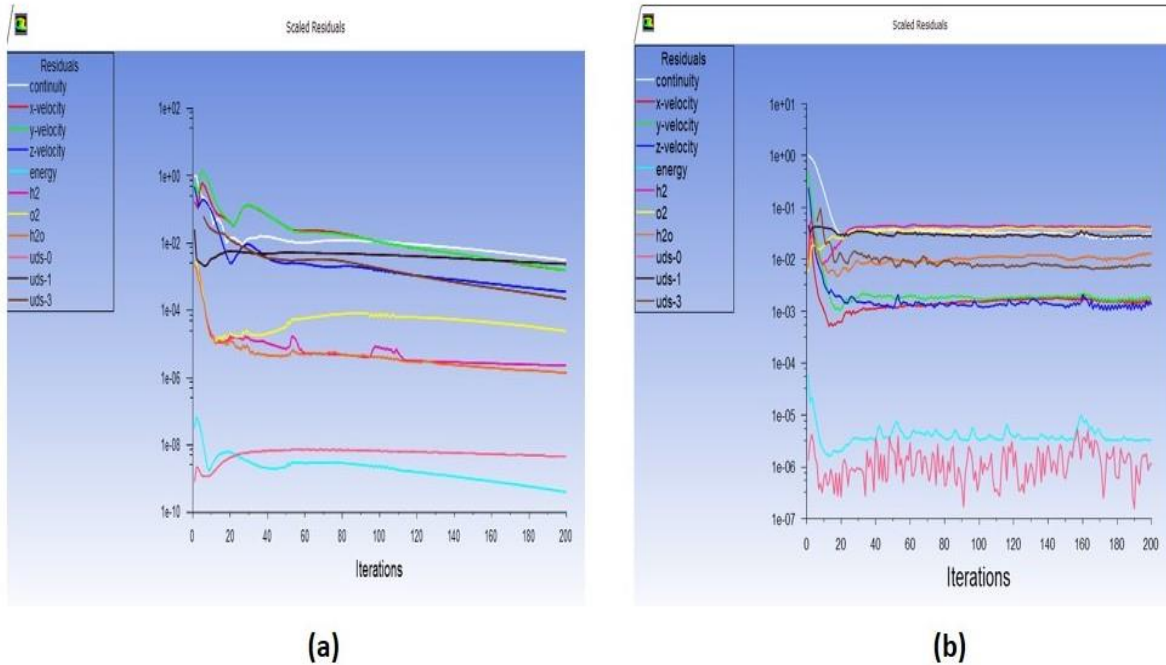
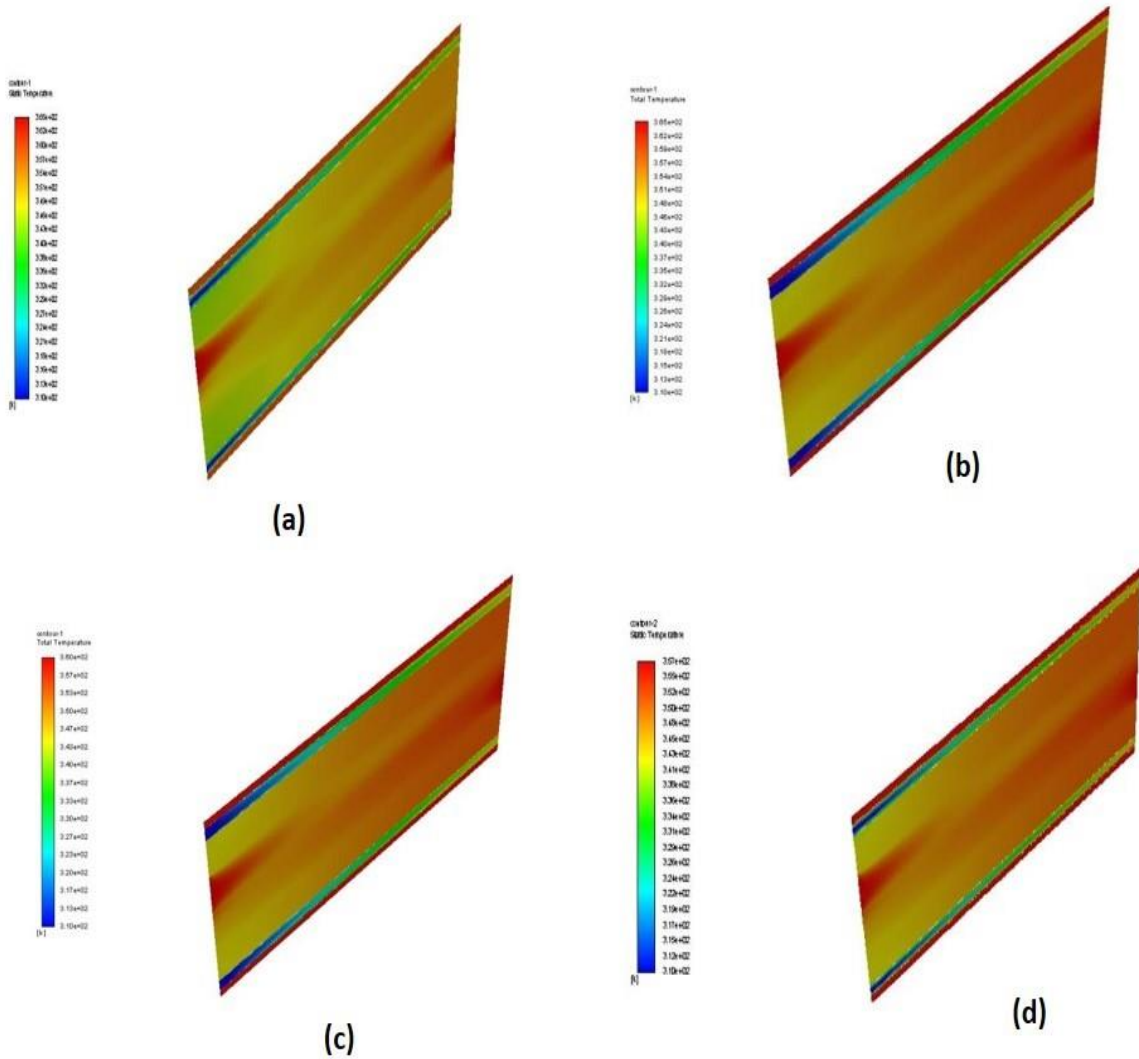


Fig 5.1.1 Iteration graphs For (a) Single fuel cell and (b) Stack

5.2 RESULT FOR SINGLE FUEL CELL

The effect of increasing the operating temperature of the PEM fuel cell device from 300 to 380 kelvin on its operation is shown in Figure. PEM fuel efficiency increases when cell temperature rises to around 357k and 362k, since water removal becomes easier and flooding is reduced. In the DI100 situation, the maximum temperature generated in the fuel cell is 371k by maintaining the regular operating temperature of 353.15k.

A maximum temperature of 365 k was reached in the PG10 condition. In the PG20 and PG30 circumstances, the highest temperature was 362 K and 357 K, respectively, lower than the original condition. As can be seen, the PG30 cooling system reached the minimum temperature. This indicates that it has a superior cooling property than the other coolants used in this study.

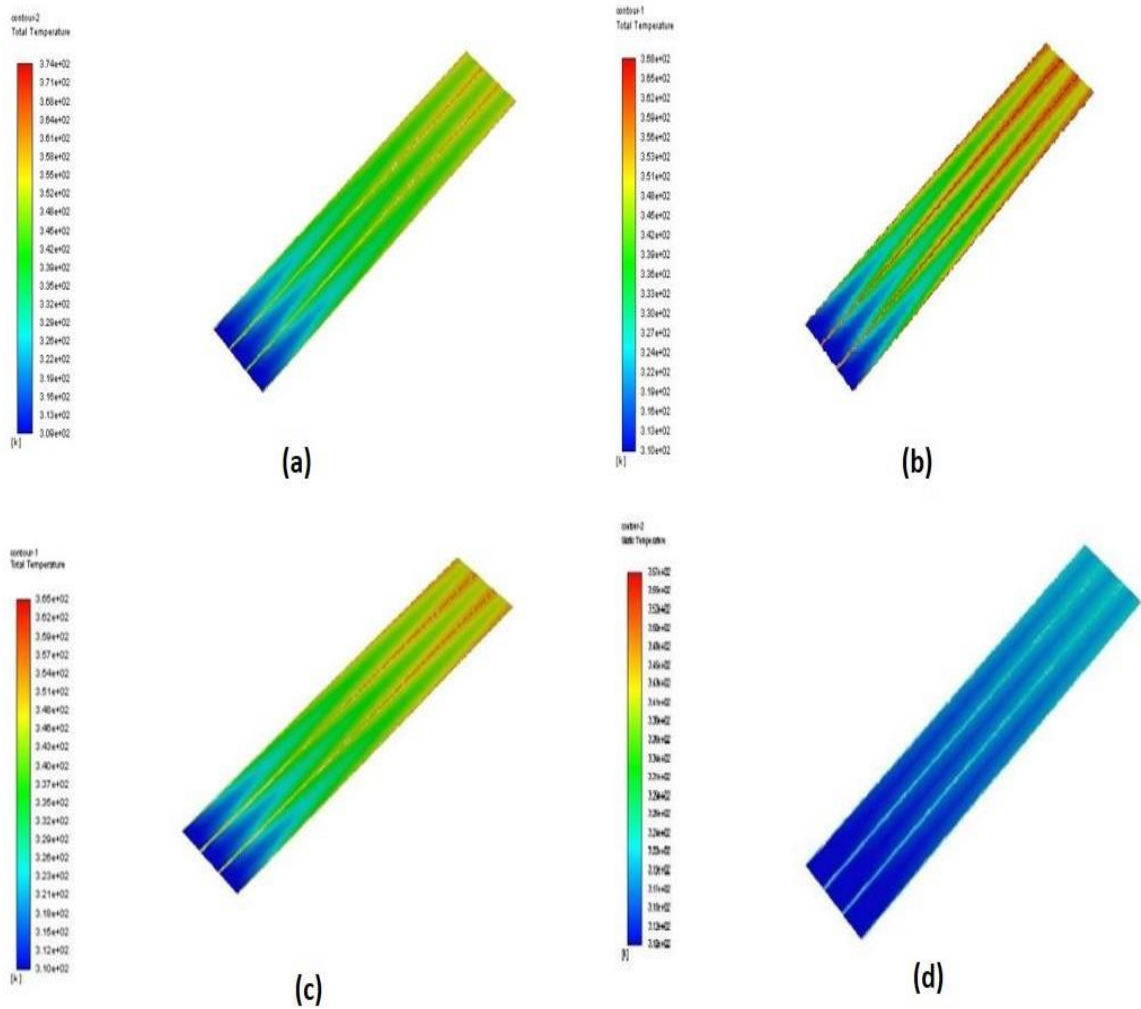


**Fig 5.2 Temperature simulation of single cell at different condition of
(a) DI100 (b) PG10 (c) PG20 (d) PG30**

5.3 RESULT FOR FUEL CELL STACK

Fig 5.3 depicts the effect of raising the PEM fuel cell device's operating temperature from 300 to 380 k on its performance. Because the other parameters, such as relative humidity and enthalpy, are appropriate, PEM fuel efficiency improves when cell temperature rises to between 365 k and 368 k. By maintaining the typical operating temperature of 360 k in the DI100 condition, the maximum

temperature generated in the fuel cell is 374 k. In the PG10 condition, a maximum temperature of 368 k was achieved. The highest temperature obtained under the PG20 and PG30 conditions was 365 k and 356 k, respectively, which was lower than the prior condition. The PG20 cooling system, as can be observed, attained the lowest temperature. This implies that it has greater cooling characteristics when compared to the other coolants utilised in this investigation.



**Fig 5.3 Temperature simulation of fuel stack at different condition of
(a) DI100 (b) PG10 (c) PG20 (d) PG30**

5.4 ANALYSIS COMPARISON OF CURRENT DENSITY VS VOLTAGE FOR (a) SINGLE CELL and (b) STACK

The Fig 5.4 depicts the current (I) generated under standard operating voltage conditions with various coolant mixtures. As Fig 5.4 shows, the current generated decreases as the coolant changes, demonstrating that temperature significantly influences current production. In this figure, the comparison between a single cell and a stack of the fuel cell.

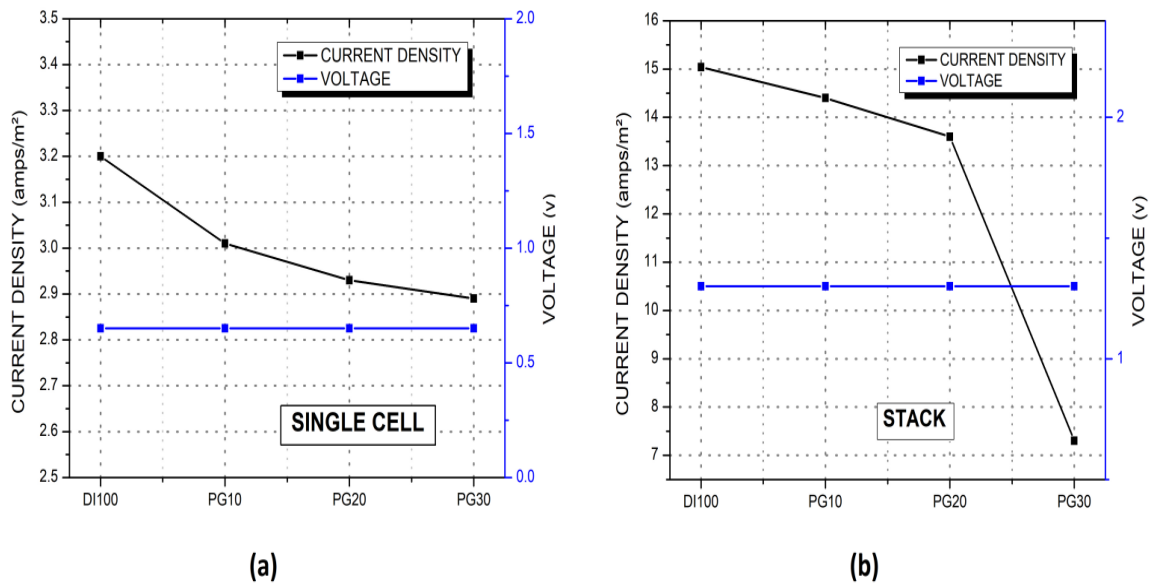


Fig 5.4 Comparison of current density Vs Voltage at (a) single cell (b) Stack

In Fig 5.4 (a) with PG 30, the results are optimal since the operating voltage is 0.65, the current generated will be below. On the other hand, Fig 5.4 (b) shows that with PG20, the results are optimal since the operating voltage is 1.3, the current generated will be higher than the single cell. Furthermore, Fig 5.4 (b) with PG30 shows the diminishing of the current value due to the temperature reduction. So, PG30 for single-cell and PG20 for stack shows promising results for better efficiency.

5.5 Analysis Comparison of Current density vs Peclet number for (a) single cell and (b) stack

The Fig 5.5 depicts the relationship between current density and pellet number in single-cell and stack fuel cells. The ratio of heat transfer advection to diffusion is measured by a peclet number, which is a dimensionless number. The stronger the effect of convection on heat transmission, the higher the Peclet number. Because the peclet number is large and the current generated is ideal, the PG30 condition produces excellent results in fig 5.5 (a).

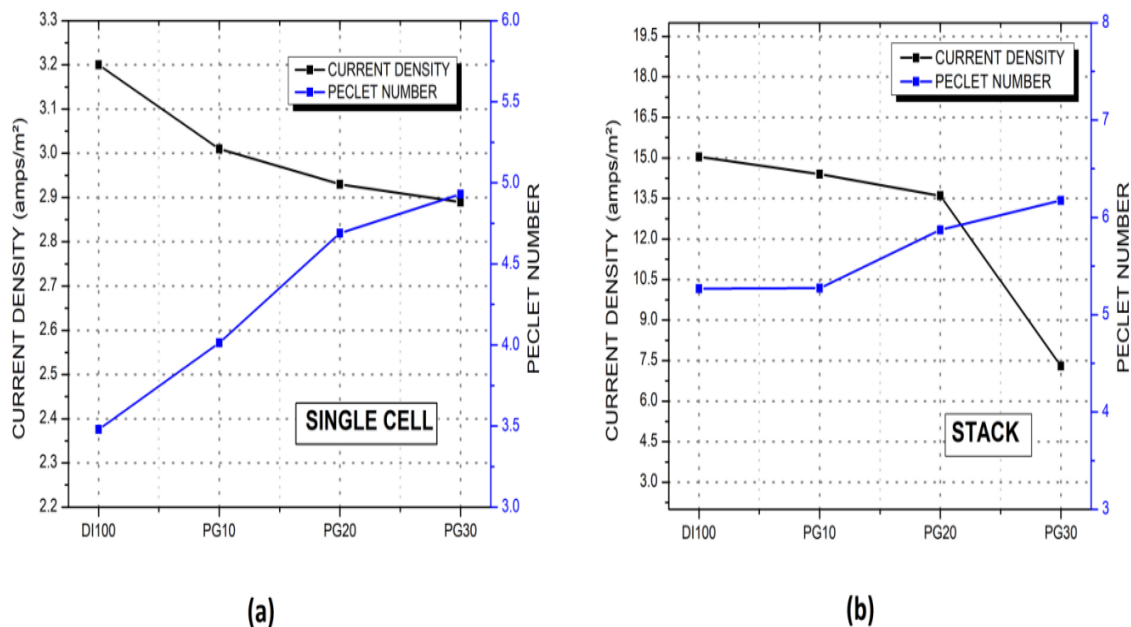


Fig 5.5 Comparison of current density Vs Peclet number at (a) single cell (b) Stack

However, the PG20 in Fig 5.5 (b) displays a good outcome. Even though the peclet number is large in PG30, the current density is lower. This demonstrates the extra heat transmission, which has an impact on the current generation. As a result, PG30 for the stack condition and for the single-cell condition, PG20 perform better.

5.6 Analysis comparison of Membrane water content vs Current density for (a) single cell and (b) stack

The relationship between Membrane water content and Current density for single-cell and stack fuel cells is shown in Fig 5.6. The amount of water in the membrane has a big impact on the fuel cell's efficiency and lifespan. Because the membrane's conductivity is heavily reliant on humidity, it must be kept hydrated. Membrane drying happens when there isn't enough water in the system, which boosts ionic resistance and exacerbates voltage drop due to ohmic losses. In the present generation, a rise in membrane water content leads to depletion.

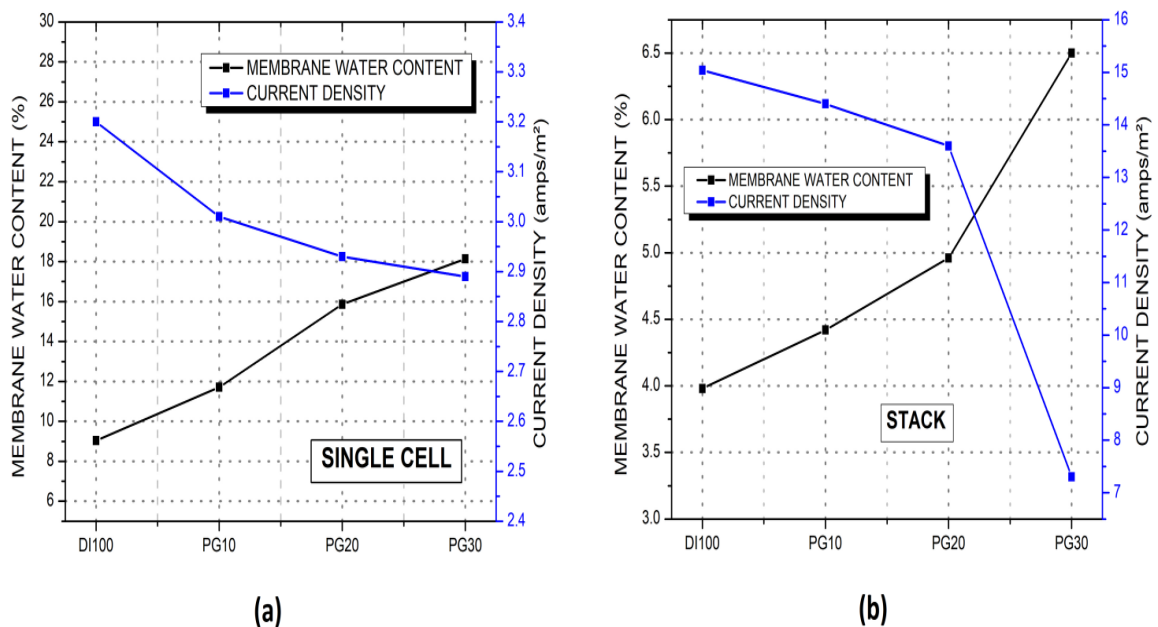


Fig 5.6 Comparison of Membrane water content Vs current density at (a) single cell (b) Stack

The membrane water content and current density parameters in Fig 5.6 (a) are ideal under the PG30 setting. For single-cell situations, this results in higher operating efficiency. On the other hand, the results obtained with PG20 were

superior; with PG30, the membrane water content is quite high, significantly reducing the current density value. As a consequence of the above mentioned graph, we can decide that PG30 for single-cell and PG20 for stack provides the best performance.

5.7 Analysis Comparison of Nusselt number vs Peclet number for (a) single cell and (b) stack

The relationship between the Nusselt number and the Peclet number for single-cell and stack fuel cells is seen in Fig 5.7. The Peclet number is a dimensionless number that indicates the ratio of heat transfer through advection and diffusion, as we all know. The greater the Peclet number, the larger the convection effect on heat transport. The Nusselt number is simply the ratio of convection heat transfer to fluid conduction heat transfer under the same conditions. Heat transfer is conduction if the Nusselt number is near to one; however, if the value is between one and ten, the slug flow is laminar. It's active convection with turbulence in the 100–1000 range if the range is larger.

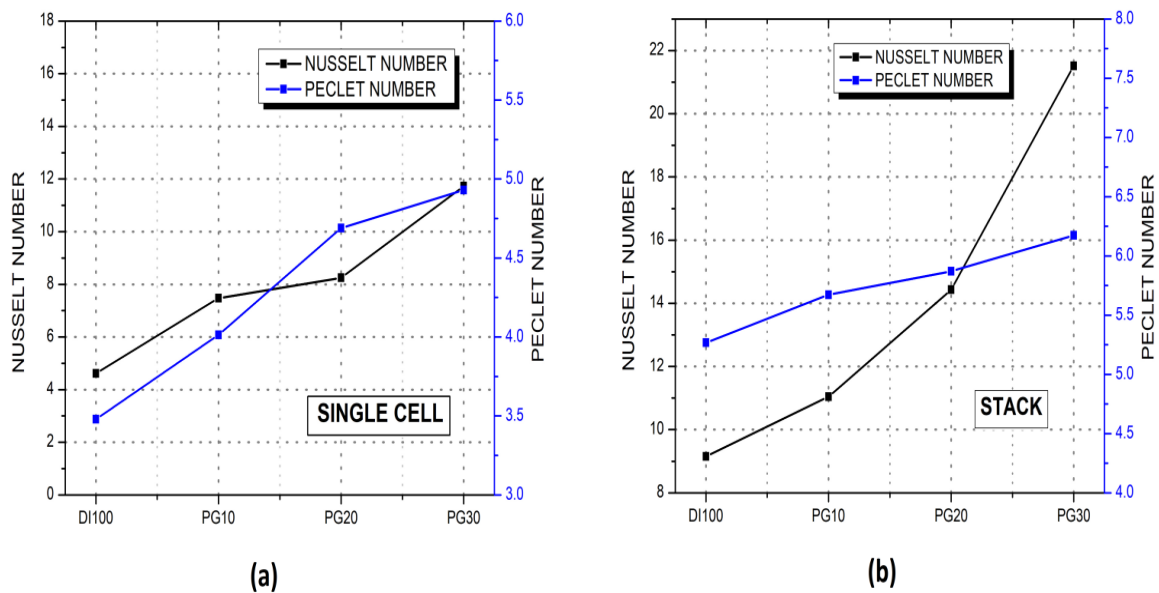


Fig 5.7 Comparison of nusselt Number Vs Peclet number at (a) single cell (b) Stack

The values obtained are ideal, as shown in Fig 5.7 (a) using PG30. When it comes to Fig 5.7(b) with PG20, however, the results are better. The Nusselt number value for PG30 is high, indicating that there is excessive convection of heat into the fluid (coolant), resulting in temperature decrease. As a consequence, the best outcomes are PG30 for single-cell and PG20 for stack Condition.

5.8 Analysis Comparison of Relative humidity vs temperature obtained for (a) single cell and (b) stack

The relationship between relative humidity and temperature for single-cell and stack fuel cells is shown in the Fig 5.8. The temperature and efficiency of the fuel cell are both influenced by relative humidity. When the RH was reduced, the membrane's proton transfer conductivity was also reduced. Lowering RH reduces electrode kinetics, such as electrode reaction and mass diffusion rates, as well as membrane proton conductivity, resulting in a considerable reduction in fuel cell performance.

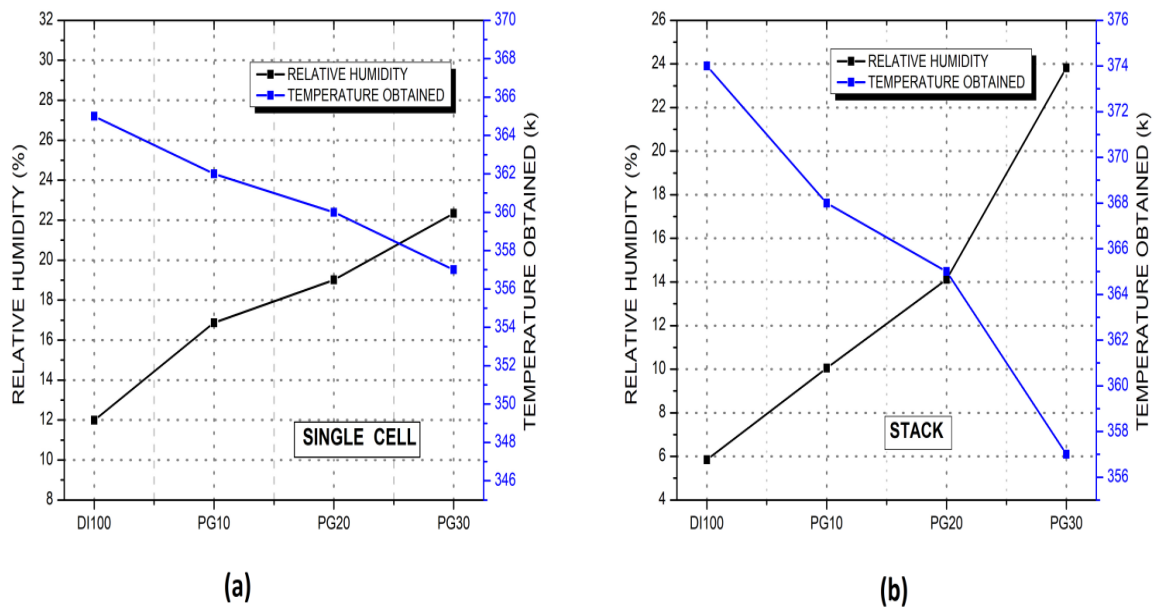


Fig 5.8 Comparison of relative Humidity Vs temperature obtained at (a) single cell (b) Stack

With PG30, the obtained values are optimal in Fig 5.8(a). The values obtained with PG20, on the other hand, are ideal for Fig 5.8(b). The obtained Relative Humidity values with PG30 are high, resulting in a temperature drop. As a result, the single-cell PG30 and stack PG20 perform better.

5.9 Analysis Comparison of Temperature obtained vs Current density for (a) single cell and (b) stack

The Fig 5.9 depicts the relationship between the temperature achieved and the current density. The current density will grow as the temperature rises. The graph depicts the current density value depletion as the temperature drops. With PG30, the obtained values are better in Fig 5.9 (a).

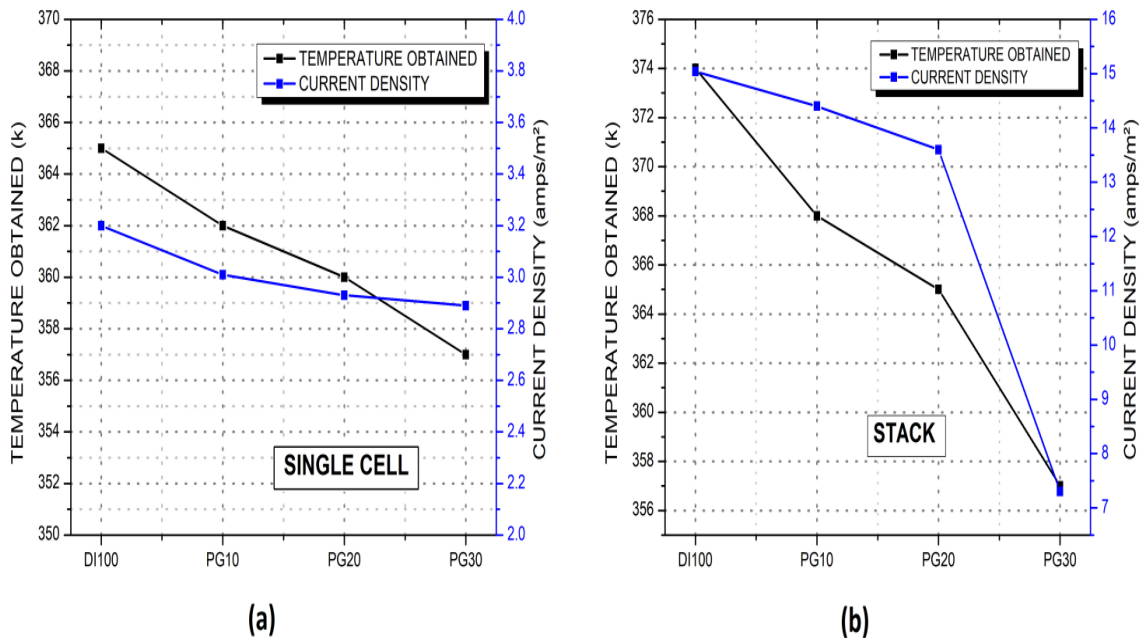


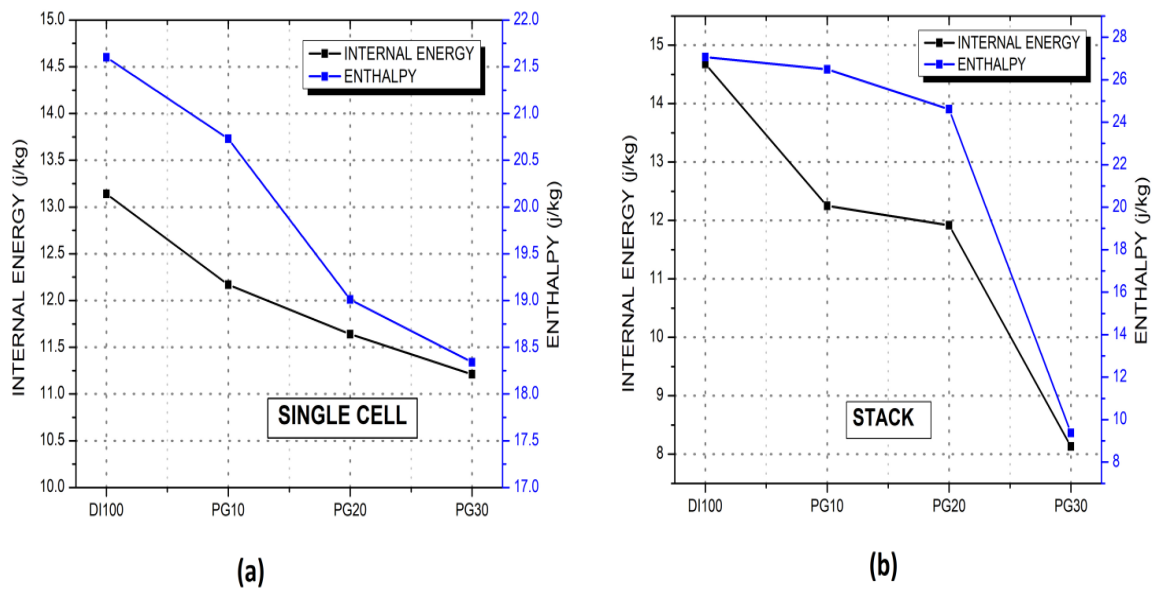
Fig 5.9 Comparison of Temperature obtained Vs current density at (a) single cell (b) Stack

Despite the fact that the current generation with DI100 is high, the temperature obtained is extremely high, resulting in a fall in Relative Humidity and Membrane Water Content measurements. The findings achieved with PG20

are displayed in Fig 5.9(b). The temperature values attained with PG30 are extremely low, resulting in a drop in current density. As a consequence, both the single-cell PG30 and the stack PG20 produce satisfactory results.

5.10 Analysis Comparison of Internal energy vs Enthalpy for (a) single cell and (b) stack

The variations in internal energy and enthalpy of single-cell and staff of the fuel cell coolant conditions are shown in Fig 5.10. For single-cell applications The outcome attained with PG30 was satisfactory. In comparison to other coolants, the enthalpy and internal energy ratios are lower in Fig 5.10 (b).



5.10 Comparison of Internal energy Vs Enthalpy at (a) single cell (b) Stack.

With PG30, a perfect balanced value is attained, increasing efficiency. However, the results produced with the PG20 stack were ideal. Because of the lower temperature, both the internal energy and the enthalpy values are lowered with PG30. As a result, the values obtained for the single-cell PG30 and stack were ideal.

CHAPTER 6

CONCLUSION

From the present work it has been concluded that , By combining operational parameters with various coolants and cooling channel designs, this research aims to develop a cooling system that will improve fuel cell performance at high operating temperatures. According to numerical studies, operating parameters like as relative humidity, peclet number, membrane water content, and temperature have a substantial impact on fuel cell performance. Using an optimiser's simple issue adjoint solution, the ideal temperature, relative humidity, and membrane water content values for numerous coolants were identified. When research elements for the unique PEM fuel cell model operating circumstances investigated in this study are combined, fuel cell productivity rises dramatically. First, the functionality is sufficient at 356 k, which was achieved using the PG30 single cell requirement. Then, as evaluated by the PG10 and PG20 circumstances, the performance improvement slowly declined from 362 k to 371 k. It's worth noting that because the membrane is dehydrated beyond 371 k, no meaningful increase in cell activity can be predicted. Similarly, at a temperature of 365 k, which is created using the PG20 stack condition, the functioning is satisfactory. After then, the performance boost gradually faded, starting at 368 k with the PG10 condition. It's worth mentioning that the PG30 condition achieves a temperature of 357 k, which is lower than the operating temperature, resulting in cell flooding. To improve PEM fuel cell performance, this study might easily be expanded to include other coolants in PEM stack systems.

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