DESIGN AND ANALYSIS OF HYDROGEN FUEL CELL VEHICLE

[1]Venkatraman R, [2]Bharath Kumar R, [3]Manojkumar N, [4]Pavithran S, [5] Manikandan S
[1]Assistant Professor, Department Of Mechanical Engineering, Knowledge Institute of Technology, Tamilnadu, India.
[2]UG Scholar,Department of Mechanical Engineering, Knowledge Institute of Technology, Tamilnadu, India.
[3]UG Scholar,Department of Mechanical Engineering, Knowledge Institute of Technology, Tamilnadu, India.
[4]UG Scholar,Department of Mechanical Engineering, Knowledge Institute of Technology, Tamilnadu, India.
[5]UG Scholar,Department of Mechanical Engineering, Knowledge Institute of Technology, Tamilnadu, India.

ABSTRACT

The hazardous effects of pollutants from conventional fuel vehicles have caused the scientific world to move towards environmentally friendly energy sources. Though we have various renewable energy sources, the perfect one to use as an energy source for vehicles is hydrogen.

A fuel cell is an electrochemical device that can produce electricity by allowing chemical gases (H_2 & O_2) and oxidants as reactants. With anodes and electrolytes, the fuel cell splits the cation and the anion in the reactant toproduce electricity.
In this project, a recent development in hydrogen fuel cell engines is reviewed to scrutinize the feasibility of using hydrogen as a major fuel in transportation systems.

So in this project, we are going to analysis the effect of different bipolar plates material such as Aluminum (Al), Copper (Cu) and Stainless Steel (SS) of a single stack of Proton Exchange Membrane (PEM) fuel cells.

Firstly, a three-dimensional (3D) PEM fuel cell model was developed and simulations were conducted using commercial Computational Fluid Dynamics (CFD) ANSYS FLUENT to examine the effect of each bipolar plate materials on cell performance. Along with cell performance, significant parameters distributions like temperature, pressure, a mass fraction of hydrogen, oxygen and water is presented.

Finally, polarization curves of three bipolar plates were drawn using the results were compared for validation and the result shows that Al serpentine bipolar plate material performed better than Cu and SS materials.

INTRODUCTION

Fuel cell vehicles (FCV) resemble normal gasoline or diesel-powered vehicles from the outside. Similar to Electric vehicles (EV), they use electricity to power a motor that propels the vehicle. Yet unlike EVs, which are powered by a battery, FCVs use electricity produced from on-board fuel cells to power the vehicle.

The fuel cell is an electrochemical device that produces electricity using hydrogen and oxygen. A fuel cell uses a catalyst to split hydrogen into protons and electrons, the electrons then travel through an external circuit (thus creating an electric current) and the hydrogen ions and electrons react with oxygen to create water.

To obtain enough electricity to power a vehicle, individual fuel cells are combined in series to make a fuel cell stack. There are different types of fuel cells, each of which is suited for a different application. Fuel cells are typically grouped according to their operating temperature and the type of electrolyte used. The amount of power generated by a fuel cell is determined by several factors including fuel cell type, size, operating temperature and pressure at which the gases are supplied to the cell. The most common type of fuel cell used in FCVs is Polymer Electrolyte Membrane (PEM).

A fuel cell is composed of an electrolyte which is placed between an anode (a negative electrode) and a cathode (a positive electrode), with bipolar plates on either side.

FUEL CELL TECHNOLOGY

A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has two electrodes, one positive and one negative, called, respectively, the anode and cathode. The reactions that produce electricity take place at the electrodes.

Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other and a catalyst, which speeds the reactions at the electrodes. Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution much of the hydrogen and oxygen used in generating electricity ultimately combines to form a harmless byproduct namely water.

A single fuel cell generates a tiny amount of direct current (DC) electricity. In practice, many fuel cells are usually assembled into a stack. Cell or stack, the principles are the same.

HOW DO FUEL CELL WORKS

The purpose of a fuel cell is to produce an electrical current that can be directed outside the cell to do work, such as powering an electric motor or illuminating a light bulb or a city. Because of the way electricity behaves, these current returns to the fuel cell, completing an electrical circuit. The chemical reactions that produce this current are the key to how a fuel cell works. There are several kinds of fuel cells and each operates a bit differently. But in general terms hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now "ionized" and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work. If alternating current is needed, the DC output of the fuel cell must be routed through a conversion device called an inverter.

Oxygen enters the fuel cell at the cathode and in some cell types (like the one illustrated above), it there combines with electrons returning from the electrical circuit and hydrogen ions that have travelled through the electrolyte from the anode. In other cell types the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with hydrogen ions.

The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances could travel through the electrolyte, they would disrupt the chemical reaction.

Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity.

Since fuel cells create electricity chemically rather than by combustion, they are not subject to the thermodynamic laws that limit a conventional power plant.

Anode: $2H_2 \Rightarrow 4H^+ + 4e^-$

Cathode: $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$

Net Reaction: $2H_2 + O_2 \Rightarrow 2H_2O$

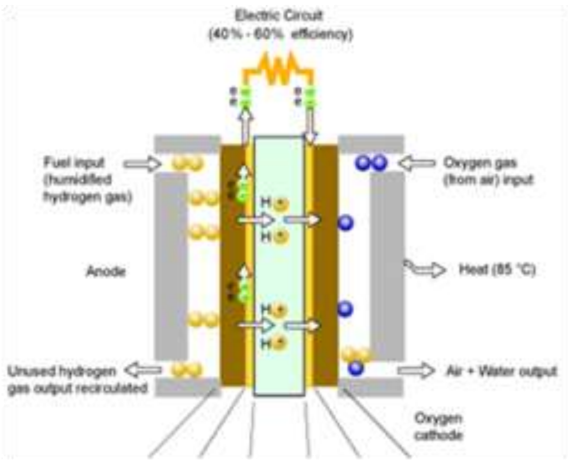


Figure 1: Fuel cell

TYPES OF FUEL CELL

- Proton Exchange Membrane Fuel Cell (PEMFC)
- Alkaline Fuel Cell (AFC)
- Molten Carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)

Proton Exchange Membrane Fuel Cell (PEMFC)

Work with a polymer electrolyte in the form of a thin, permeable sheet. Efficiency is about 40 to 50 percent, and operating temperature is about 80 ºC (about 175 degrees F). Cell outputs generally range from 50 to 250 kW. The solid, flexible electrolyte will not leak or crack and these cells operate at a low enough temperature to make them suitable for homes and cars. But their fuels must be purified and a platinum catalyst is used on both sides of the membrane, raising costs.

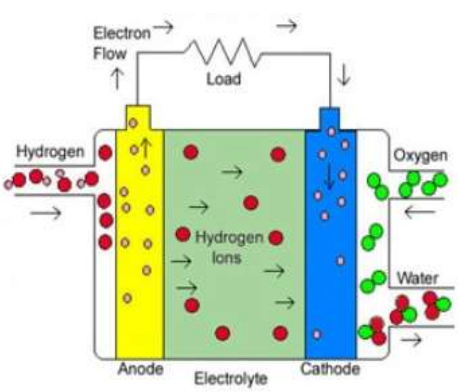


Figure 2: Schematic Diagram of PEMFC

Alkaline Fuel Cell (AFC)

They operate on compressed hydrogen and oxygen. They generally use a solution of potassium hydroxide (chemically, KOH) in water as their electrolyte. Efficiency is about 70 percent and operating temperature is 150 to 200 ºC (about 300 to 400 degree F). Cell output ranges from 300 watts (W) to 5 kilowatts (kW). Alkali cells were used in Apollo spacecraft to provide both electricity and drinking water. They require pure hydrogen fuel, however and their platinum electrode catalysts are expensive. And like any container filled with liquid, they can leak.

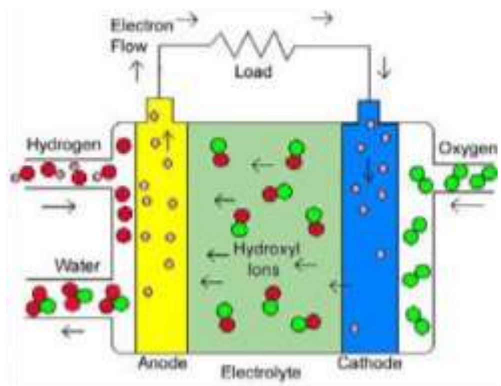
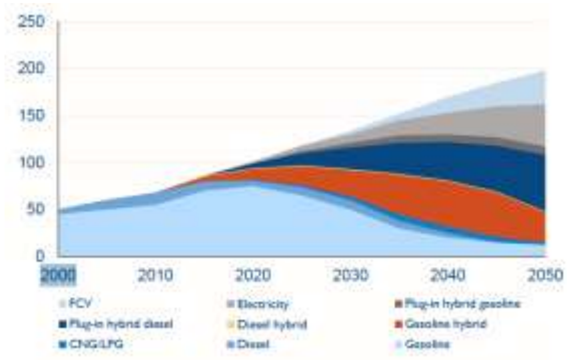


Figure 3: Schematic Diagram of AFC

FCV sales volumes are projected to be significant, but only in the long term, even with a favorable climate-policy scenario. Fig.1.6 shows FCV sales volume anticipated based on a long-term powertrain mix scenario. Considering a similar scenario, the international energy agency (IEA) anticipates an FCV market share of about 17 % by 2050 (35 million annual unit sales).



X axis = Time in years Y axis = Sales volume

Figure 4: Graphical Representation of Fuel cell vehicles (FCV) sales volume

LITERATURE REVIEW

Aditya Kumar Jha, Aashish Nagpal (2019) has proposed "Hydrogen Production, Storage, Transportation, Its Economy and Fuel Cell: A Review" Hydrogen is a soaring quality energy carrier that could be created at global scale, via thermo chemical processing of hydrocarbons, such as natural gas, coal or biomass or water electrolysis using any source of electricity including renewable, such as wind or solar, or nuclear power. Hydrogen can be renewed to electricity and heat in fuel cells at high efficiency with zero end-use emissions. In this paper we review the hydrogen production technique which is about fuel cell technology. The different types of fuel cells like MCFCs, SOFCs, PEMFCs, hydrogen economy, hydrogen storage and transportation &its use in fuel cell vehicles.

Tolga TANER (2019) has proposed "The Flow Channel with Nafion Membrane Material Design of PEM Fuel Cell" This study is about flow channels in the design of the PEM (Proton Exchange Membrane) fuel cell system. In the experimental study, different flow geometry, Nafion membrane and bipolar plate gas diffusion channel designs are available. The aim of this study is to determine the cost-benefit analysis of PEM fuel cell with a combined flow channel design. In addition, the simple payback period was found to be 0.81. Thus, the PEM fuel cell was determined by the techno-economic analysis calculation, in which energy savings can be achieved by the flow channel design.

Raluca-Andreea Felseghi , Elena Carcadea, Maria Simona Raboaca (2019) has proposed "Hydrogen Fuel Cell Technology for the Sustainable Future of Stationary Applications", the climate changes that are becoming visible today are a challenge for the global research community. The stationary applications sector is one of the most important energy consumers. This article reviews the specific characteristics of hydrogen energy, which recommends it as a clean energy to power stationary applications. The aim of review was to provide an overview of the sustainability elements and the potential of using hydrogen asan alternative energy source for stationary applications and for identifying the possibilities of increasing the share of hydrogen energy in stationary applications, respectively.

W.R.W.Daud, E.Rosli, E.H.Majlan,R.Mohamed (2017) has proposed "PEM fuel cell system control: A review", although the Proton Exchange Membrane Fuel Cell (PEMFC) is still attracting enormous R&D interest because of its high energy density, its commercialization is hampered by many challenges including cutting cost, improving performance and increasing durability. While they could be solved by material selection, the durability of PEMFC is also affected by voltage reversals and fuel starvation. In this paper, PEMFC control sub-systems namely the reaction, thermal, water management and power electronic subsystems are reviewed critically, with special attention on control strategies to avoid fuel starvation. Classical Proportional Integral and Derivative (PID) controllers are commonly used in feedback voltage control and feed- forward current control by manipulating hydrogen and air flow rates.

M.Abdollahzadeh J.C. Pascoa A.A. Ranjbar Q. Esmailic (2016) has proposed "Analysis of PEM Fuel Cell Cathode Two-Dimensional Modeling" the performance of PEMFC (Polymer Electrolyte Membrane Fuel Cells) with different configuration of gas feeding channels is investigated. Multi-component mixture model is used in order to simulate the two-phase flow and transport in cathode gas diffusion layer of PEM fuel cell. This model reduces the numerical simulation complexity by reducing the number of nonlinear governing equations. A wide detailed parametric study is done to investigate different operational parameter such as pressure difference, operating temperature, different geometrical parameters such as gas diffusion layer thickness and various material parameters such as porosity and wettability. Computational simulations have been conducted and the simulation results were compared with the available results in literature and showed very little difference. Results have been presented with different polarization curves, power density and local current density curves and also the plots of saturation level at catalyst layer surface.

COMPONENTS

The fabrication of "Design and Analysis OF Hydrogen FuelCell Vehicle consists of the following components to full fill the requirements

The project consist the following parts

- Buck Converter
- Battery
- Throttle Controller
- Electric Controller
- Hub Motor
- Hydrogen Cylinder

DESCRIPTION OF COMPONENTS

BUCK CONVERTER

A buck converter (step-down converter) is a DC to DC power converter which steps down voltage (while drawing less average current) from its input (supply) to its output (load). It is a class of Switched-Mode Power Supply typically containing at least two semiconductors (a diode and a transistor, although modern buck converters frequently replace the diode with a second transistor used for synchronous rectification) and at least one energy storage element, a capacitor, inductor or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

Figure 5: Buck converter

BATTERY

A battery is a device consisting of one or more electrochemical cells with external connections for powering electrical devices such as flashlights, mobile phones, and electric cars. When a battery is supplying electric power, its positive terminal is the cathode and its negative terminal is the anode. The terminal marked negative is the source of electrons that will flow through an external electric circuit to the positive terminal. When a battery is connected to an external electric load, a redox reaction converts high-energy reactants to lower-energy products and the free-energy difference is delivered to the external circuit as electrical energy. Historically the term "battery" specifically referred to a device composed of multiple cells, however the usage has evolved to include devices composed of a single cell.

Figure 6: Battery

THROTTLE CONTROLLER

Electronic Throttle Control (ETC) is an automobile technology which electronically "connects" the accelerator pedal to the throttle, replacing a mechanical linkage. A typical ETC system consists of three major components:

(i) an accelerator pedal module (ideally with two or more independent sensors),

(ii) a throttle valve that can be opened and closed by an electric motor (sometimes referred to as an Electric or Electronic Throttle Body) and

(iii) a Power train or Engine Control Module. The ECM is a type of Electronic Control Unit (ECU), which is an embedded system that employs software to determine the required throttle position by calculations from data measured by other sensors, including the accelerator pedal position sensors, engine speed sensor, vehicle speed sensor and cruise control switches. The electric motor is then used to open the throttle valve to the desired angle via a closed-loop control algorithm within the ECM.

ELECTRIC CONTROLLER

Simply put, a DC motor controller is any device that can manipulate the position, speed or torque of a DC-powered motor. There are controllers for brushed DC motors, brushless DC motors, as well as universal motors and they all allow operators to set desired motor behavior even though their mechanisms for doing so differ.

HUB MOTOR

The wheel hub motor (also called wheel motor, wheel hub drive, hub motor or in-wheel motor) is an electric motor that is incorporated into the hub of a wheel and drives it directly.

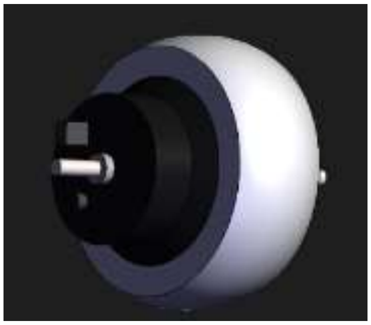
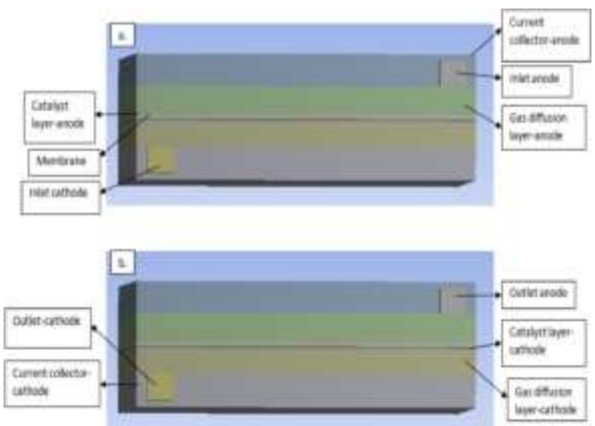


Figure 7: Hub motor

HYDROGEN CYLINDER

Cylinder made from composite material,



fiberglass/aramid or carbon fiber with a metal liner (aluminum or steel).

Figure 8: Hydrogen Cylinder

GEOMETRY DESIGN

The geometry model was built using SOLID WORKS 2016 version software. Then the geometry was generated in this software and relevant zones which are used for the modeling domains such as current collectors, flow field channels, gas diffusion layers, catalyst layers and membrane for both, After, the grid was exported to ANSYS FLUENT 18.0 licensed software, where the meshing and complete set of the module was solved. ANSYS provides an additional add-on PEM fuel cell module, which was used in solving the fluid-based equation for the fuel cell. The models were read into the FLUENT application, then various specifications and boundary conditions were set for each zone.

This numerical model domain is single cell geometry. The reactant gases for this model are humidified hydrogen and air. The mass flow inlet was controlled using stoichiometry numbers of 0.6 at the anode side and 0.4 at the cathode side. The operating temperature was 323, 333 and 353 K. While the operating pressure was 150, 200, 250 kPa, respectively. The active area for the model is 55 cm^2; the channels are 2 mm in width and 2 mm in depth. The rib width is 2 mm. Table 1 shows the parameters for simulation.

Figure 9: A 3D view of the single PEM fuel cell and its components. (a) Inlet channel (b) outlet channel

Table 1: Parameters for simulation

Parameters	Value	Unit
Operating Temperature	298/323/338	K
Operating Pressure	1.5/2.0/2.5	Bar
Mole fraction hydrogen and water vapour (anode)	0.6/0.4	-
Mole fraction for oxygen and water vapour (cathode)	0.20.15	-
Relative humidity at anode	100	%
Relative humidity at cathode	100	%
Open circuit	0.7	V

COMPUTATIONAL DOMAIN

A three-dimensional model for a PEM fuel cell was used in this study. The geometry model of the single fuel cell with parts consisting of anode and cathode current collectors, gas flow channels, Gas Diffusion Layers (GDLs), Catalyst Layers (CLs) and the membrane was merged and meshed through the FLUENT mesh interfaces operation. It was carried out using the automatic meshing method and the size function of the model was set to uniformity.

The relevance centre were set as fine and the element order was linear. The transition was set to fast. This setting ends up to have 59, 160 nodes and 85, 173 elements. The total computational domain consists of 41, 999 grid cells.

BOUNDARY CONDITIONS

The mesh was exported to FLUENT setup function to start iterations after it was found suitable. The boundary conditions are defined as follows: constant anode and cathode mass flow rate at both the inlet gas channels and constant pressure state of the channel's outlet. The model external surfaces are assumed as a wall. The Multi-grid cycle function was altered to F-cycle for simulation stabilization in the process of ANSYS FLUENT PEM fuel cell simulation and the method for all specified equations. The F-cycle was selected in order to intensify the parallel computing. Water saturation, species concentration, protonic and electronic potential used bi-conjugate gradient stabilization, this is because it provides better convergence results when compared to any other stabilization processes.

The anode and cathode region of the reactant inlet conditions are mass flow inlet category; the pressure outlet was selected as the gases outlet. The operational temperature and pressure for each bipolar plate materials were compared as shown in Table 1, for the anode and cathode region of the fuel cell. The numerical proceedings for every parameter in the computational domain for the boundary conditions and cell voltage at the cathode are set with the transport and momentum equations for all the species are resolved. In the computational domain, all species distribution is acquired, then the process is repeated until convergence is obtained.

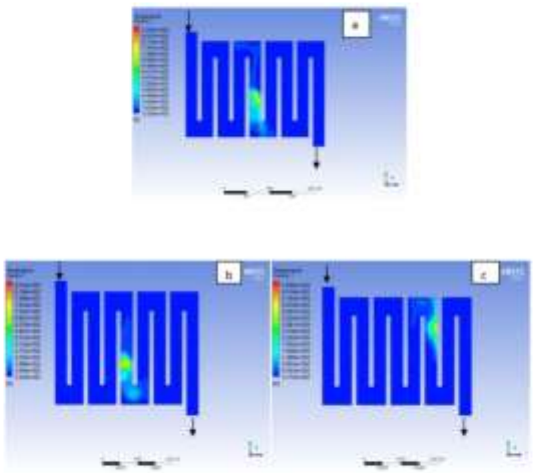
CFD ANALYSIS RESULTS EFFECTS OF OPERATING TEMPERATURE VARIATION

The operating temperature does play a vital role in improving fuel cell performance. In PEM fuel cell, increasing the operating temperature is beneficial in enhancing electrochemical reaction, ionic transport rate and the removal of water from the fuel cell. Similarly, the fuel cell temperature can affect membrane life span and performance because if the membranes gets dry and stays like that for a long time, this may result in rupturing of the membrane. When observing the impact of the operating temperature on the cell performance, other parameters were kept constant while only the temperature was varied.

The contours for temperature distribution in the channels for aluminum, copper and steel materials are shown in Figures 10 - 15, respectively, for both anode and cathode side at temperatures of 298, 323 and 338 K at 0.7 V.

The temperature distribution increases with increase in temperature. It can be observed at the interface between the catalyst layer and membrane in the anode region of each material that the temperature distribution is slightly different across each flow field channels and having temperature variations between 1 and 6 K. However, it was noticed that the highest temperature is at the cathode side for various materials temperature distribution in the channel due to electrochemical reaction and ohmic heating taking place.

It is observed for Al material that the temperature at 338 K rises to 994 K, which is the highest



temperature distribution variation, while at temperature 298 K steel materials has the lowest temperature distribution variation of 221 K among all other materials. The 3D numerical simulation temperature contours result shows that reactant adsorption on material surfaces has a significant effect on cell performance.

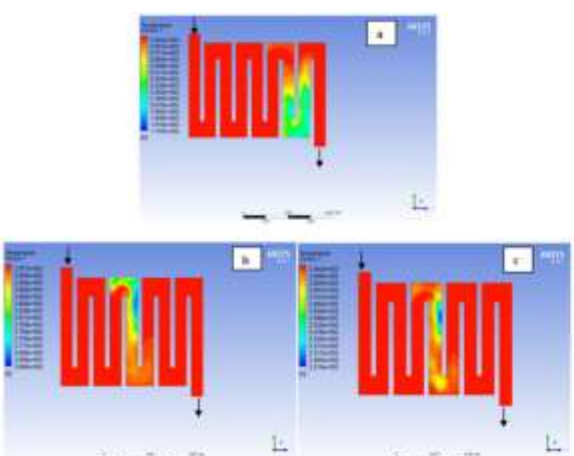
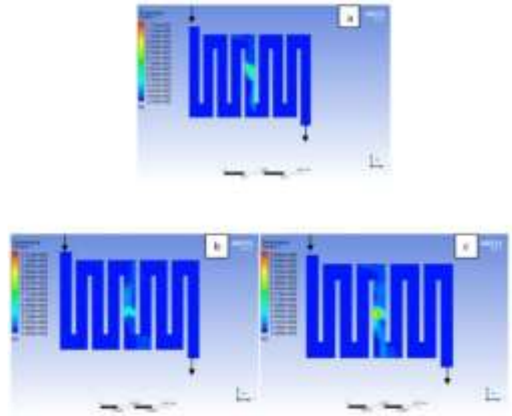


Figure 10: Temperature distribution at the anode



region for each material at 298K: (a) Aluminum, (b) Copper, (c) Steel.

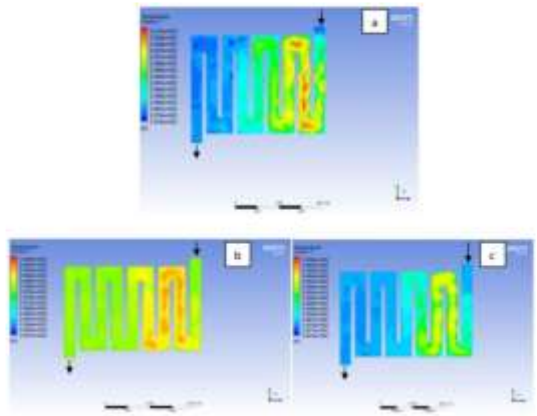


Figure 11: Temperature distribution at the cathode region for each material at 298K: (a) Aluminum, (b) Copper, (c) Steel.

Figure 12: Temperature distribution at the anode region for each material at 323K: (a) Aluminum, (b) Copper, (c) Steel.

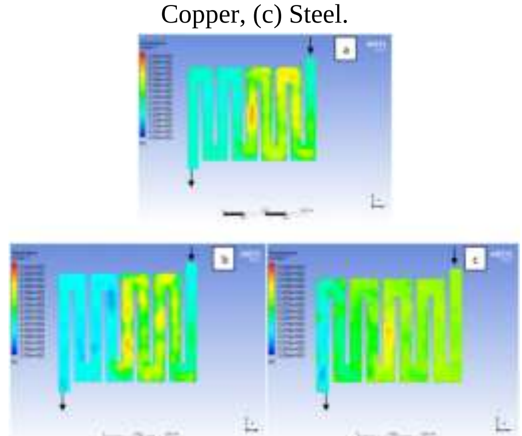


Figure 13: Temperature distribution at the cathode region for each material at 323K: (a) Aluminum, (b) Copper, (c) Steel.

Figure 14: Temperature distribution at the cathode region for each materials at 338K: (a) Aluminum, (b) Copper, (c) Steel.

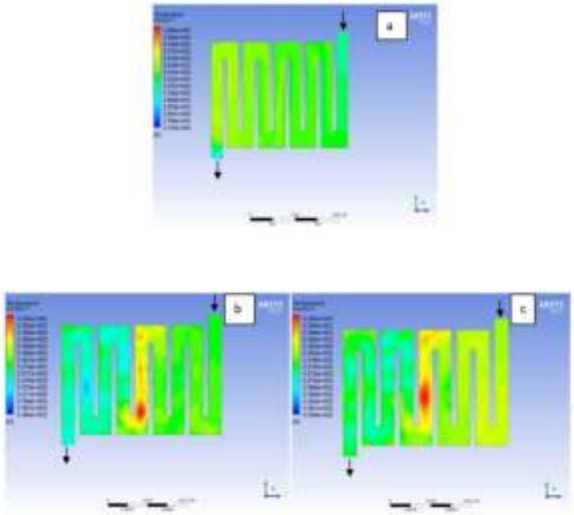


Figure 15: Temperature distribution at the cathode region for each material at 338K: (a) Aluminum, (b) Copper, (c) Steel.

EFFECTS OF OPERATING PRESSURE VARIATION

Fuel cell operation could be at ambient pressure or pressurized state. Increase in pressure improves cell performance. The reactant in flow pressure is always higher than the outflow pressure as a result of pressure drop within the flow field channels. Among the significant parameter that needs to be taken into account when designing a PEM fuel cell is pressure drop. The flow field channel is often the place where the pressure drop does take place and it does affect the electrochemical reaction of the fuel cell. Figures 16 – 21 shows the pressure drop at both anode and cathode channel at 1.5, 2.0 and 2.5 bar, respectively.

The pressure drop is more at the inlet flow and gradually decreases along the outlet flow channel for all the bipolar plate materials. It is observed that Al material has the least significant pressure drop at a different pressure range of the fuel cell than Cu and SS bipolar plate material. Besides bending and frictional losses, the adsorptions of the reactants at the surface of the bipolar plate materials have contributed to the results. Moreover, a comparison between the anode and the cathode for each design revealed that the pressure at the anode decreases as the voltage decreases because the hydrogen must satisfy the current demanded by the cell.

On the contrary, the gas pressure at the cathode increases as the voltage decreases due to the water generation in the electrode that causes a pressure rising in the flow channels.

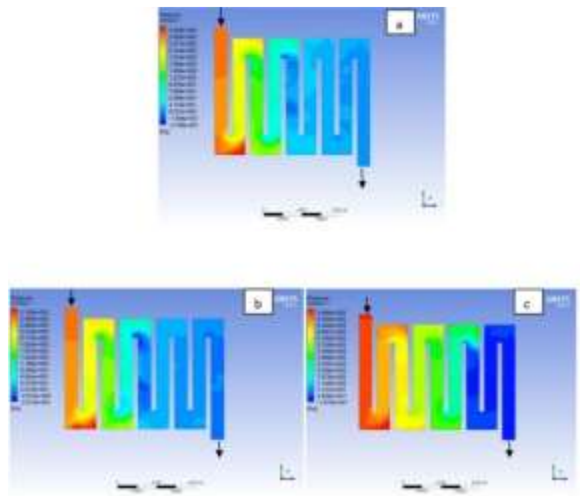


Figure 16: Pressure distribution at the anode region for each material with temperature 323 K at 1.5 bar: (**a**) Aluminum, (**b**) Copper, (**c**) Steel.

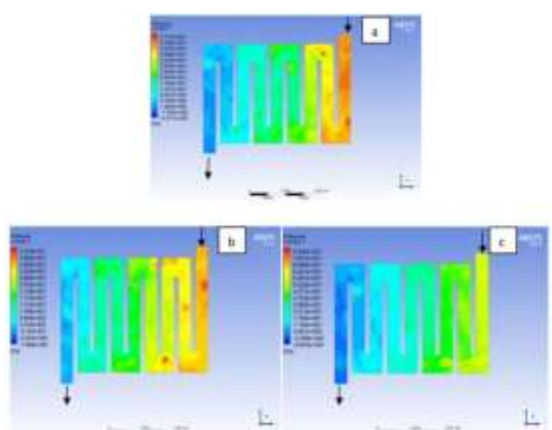


Figure 17: Pressure distribution at the cathode region (GDL/CL) for each material with temperature 323 K at 1.5 bar: (**a**) Aluminum, (**b**) Copper, (**c**) Steel.

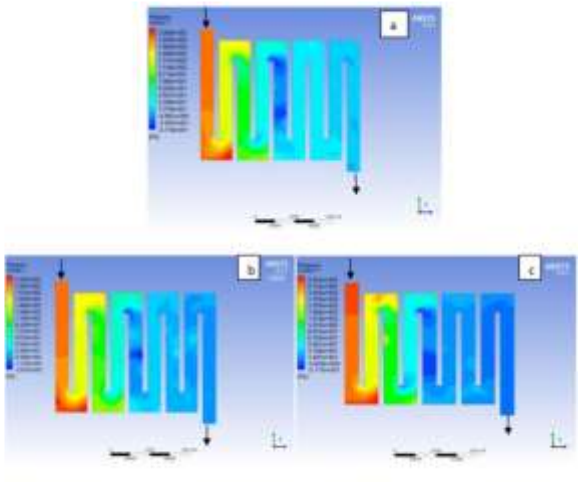
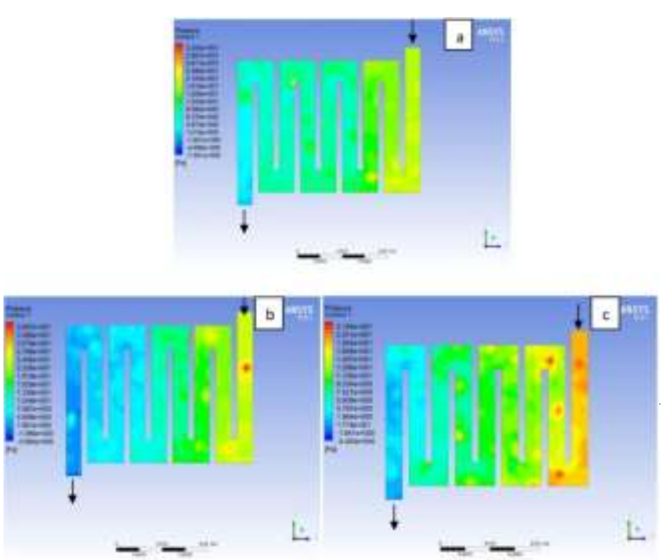


Figure 18: Pressure distribution at the anode region (GDL/CL) for each material with temperature 323 K at 2.0 bar: (**a**) Aluminum, (**b**) Copper, (**c**) Steel.

Figure 19: Pressure distribution at the cathode region for each material with temperature 323 K at 2.0 bar: (**a**) Aluminum, (**b**) Copper, (**c**) Steel.



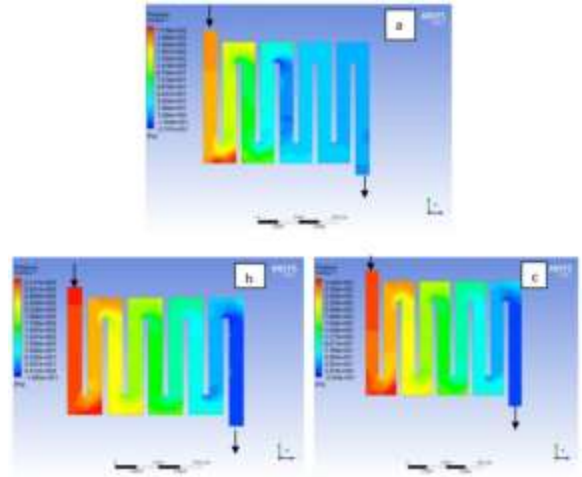
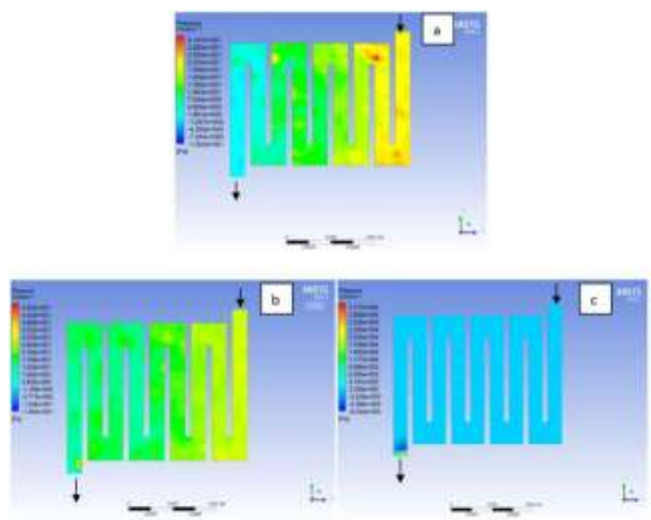


Figure 20: Pressure distribution at the anode region for each material with temperature 323 K at 2.5 bar: (**a**) Aluminum, (**b**) Copper, (**c**) Steel.

Figure 21: Pressure distribution at the cathode region for each material with temperature 323 K at 2.5 bar: (**a**) Aluminum, (**b**) Copper, (**c**) Steel.



MASS FRACTION

The reactant gas distribution across the catalyst layers is among the factors that could be used to examine a fuel cell performance due to its effect on the current density generated. A gas distribution that is uniform will prolong the membrane electrolyte assembly life-span and improve the overall performance of the fuel cell. In addition, bipolar material and the interaction with reactant supply to the catalyst layer for the electrochemical reaction will affect the cell performance. Here, different bipolar plate material at both electrodes catalyst layer with a constant operating voltage of 0.7 V at a temperature of 323 K and a pressure 1.5 bar is examined.

Hydrogen is known to be the lightest element in the universe; for this reason; it diffuses in any environment readily. As can be seen in Figure 22 hydrogen concentration depleted at the middle of the channel where the catalyst layer is located, which was consumed for an electrochemical reaction from the inlet to the outlet fluid channel for the materials as a result of consumption of reactant due to reaction. On closer inspection, it is revealed that Al and Cu material followed a similar trend, in the sense that the consumption rate of hydrogen for Al material was slightly higher than Cu and SS material. The oxygen mole fraction for the different materials is shown in Figure 23.

It can be seen that the oxygen mole fraction rate is high at the inlet channels for all the various materials and decreases gradually throughout the channels to the outlet channels due to the electrochemical reaction taking place at the cathode side of the fuel cell. It is noticed that the oxygen consumption rate for Al material is more than other materials. The more the consumption rate of reactant the more the current will be generated.

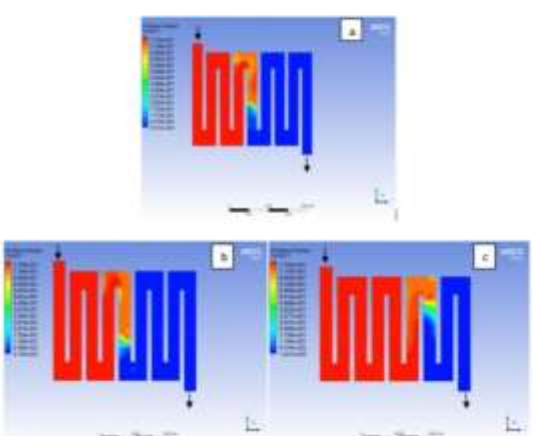
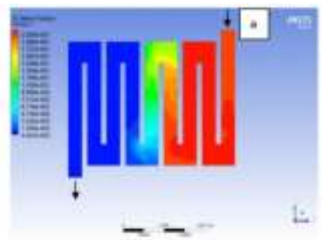


Figure 22: Contours of hydrogen mass fraction at the anode region for each material with temperature 323 K at pressure 1.5 bar: (a) Aluminum, (b) Copper, (c) Steel.



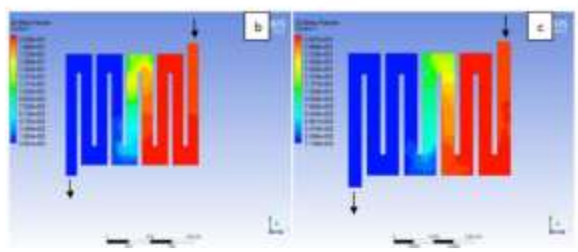


Figure 23: Contours of oxygen mass fraction at the cathode region for each material with temperature 323 K at pressure 1.5 bar: (a) Aluminum, (b) Copper, (c) Steel

The membrane needs to be sufficiently hydrated so that the ionic transport from anode to cathode side will not be hindered. However, too much hydration of the membrane could lead to flooding of the MEA, which would affect the fuel cell performance. In Figure 24 the water on membrane mass fraction distribution is at cell potential 0.7 V. It is noticed that the water content in the membrane is more in the Al material than Cu and SS materials. A particular amount of water is needed for membrane hydration and it improves the ionic conductivity across the membrane, which will influence the fuel cell power output. It is also observed that Cu and SS material has more zones where the membrane is experiencing dryness than Al material as a result of activation losses or temperature of the cell. More water uniformity in the membrane can be found in the Al material than its counterpart, which will contribute to the overall cell performance.

MODELING RESULTS VALIDATION

Figure 25 presents the comparison between the modeling findings polarisation curve results of the fuel cell performance. Some of these materials were integrated into ANSYS software in order to simulate and find out the best material cell performance. A serpentine flow field plate was used with an anode and cathode parallel flow. A single cell with a serpentine flow channel with the co-counter flow was used.

It is observed that the materials followed a similar behavior and the effect of each material at low current density can be negligible but at a higher current density, the effect of the material on cell performance is significant. The Al material performed better than Cu and SS throughout the operating condition, which can be attributed to low mass transport losses. Their results show that hydrogen adsorption on Al surfaces is more stable than other metals. So, concluded that hydrogen atoms bond weakly to Cu surfaces. Since SS is an alloy metal, this contributes to the reason why it has the lowest fuel cell performances. In addition, SS surface interactions with hydrogen atoms will result in high instability. The peak powers percentage difference for various materials between simulation and experimental results are illustrated in Table 2.

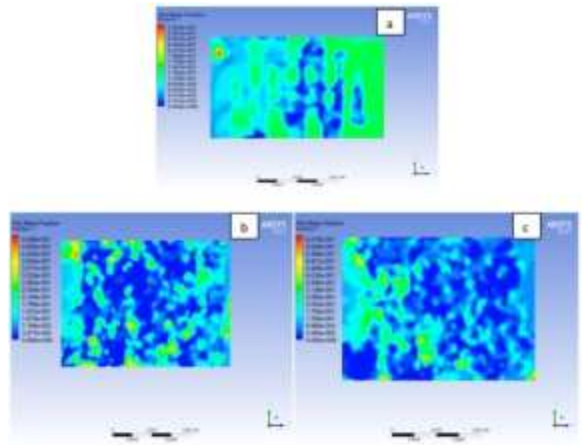


Figure 24: Water mass fraction at the membrane for (a) Aluminum, (b) Copper, (c) Steel bipolar plate materials at 338 K, 1.5 bar.

Table 2. Peak power data is for simulation and experimental results for the three bipolar plate materials.

Materials	Peak power (sim.)	Peak power (exp.)	% deviation b/w sim. and exp.
Aluminium	0.36	0.33	8.33
Copper	0.3	0.28	6.67
Steel	0.25	0.23	8.00

CONCLUSION

A low-cost bipolar plate material with a high fuel cell performance is important for the establishment of PEM fuel cells into the competitive market world. A Computational Fluid Dynamics (CFD) investigation was conducted to examine the effect of different bipolar plates materials of aluminum, copper and stainless steel on a single cell of Proton Exchange Membrane (PEM) fuel cells performances. The solutions from the PEM fuel cell model of various variables and polarization curves were derived.

It was observed that the Al bipolar plate material temperature distribution in the fuel cell was the best and it has the lowest pressure drop than Cu and SS material. It is worth nothing that in terms of

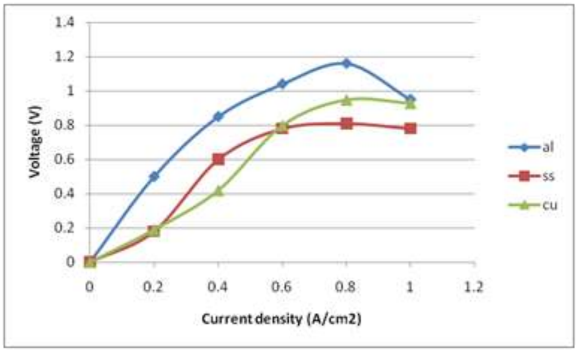


Figure 25: Polarization Curve for Three Bipolar Materials

hydrogen, oxygen and water vapor distributions the Al bipolar plate shows a better uniformity; which will increase the ionic conductivity in the membrane. Similarly, the simulation results showing that Al bipolar plate have the best overall PEM fuel cell performance. The finding is related to literature experimental results on adsorption of metal surfaces, which shows that hydrogen molecules is more stable on Al surface than Cu and SS surfaces. Hence, Al bipolar plate material can be considered to be used as the best bipolar plate material, especially for portable applications due to it light weight and reasonable cheap price of material.

BIBLIOGRAPHY

[1]Abdelkareem, M.A.; Lootah, M.A.; Sayed, E.T.; Wilberforce, T.; Alawadhi, H.; Yousef, B.A.A.; Olabi, A.G. Fuel cells for carbon capture applications. Sci. Total Environ. 2021, 769, 144243.

[2]Abdelkareem, M.A.; Wilberforce, T.; Elsaid, K.; Sayed, E.T.; Abdelghani, E.A.M.; Olabi, A.G. Transition metal carbides and nitrides as oxygen reduction reaction catalyst or catalyst support in proton exchange membrane fuel cells (PEMFCs). Int. J. Hydrog. Energy 2020, in press.

[3]Baroutaji, A.; Arjunan, A.; Alaswad, A.; Praveen, A.S.; Wilberforce, T.; Abdelkareem, M.A.; Olabi, A.G. Materials for fuel cell membranes. Ref. Modul. Mater. Sci. Mater. Eng. 2020.

[4]Hong, L.; Peiwen, L.; Jon, V.L. CFD study on flow distribution uniformity in fuel distributors having multiple structural bifurcations of flow channels. Int. J. Hydrog. Energy 2010, 35, 9186–9198.

[5]Karimi, S.; Fraser, N.; Roberts, B.; Foulkes, F.R. A review of metallic bipolar plates for proton exchange membrane fuel cells: Materials and fabrication methods. Adv. Mater. Sci. Eng. 2012.

[6]Olabi, A.G.; Wilberforce, T.; Abdelkareem, M.A. Fuel cell application in the automotive industry and future perspective. Energy 2021, 214, 118955.

[7]Olabi, A.G.; Wilberforce, T.; Sayed, E.T.; Elsaid, K.; Abdelkareem, M.A. Prospects of Fuel Cell Combined Heat and Power Systems. Energies 2020, 13, 4104.

[8]Sun, H.; Cooke, K.; Eitzinger, G.; Hamilton, P.; Pollet, B. Development of PVD coatings for PEMFC metallic bipolar plates. Thin Solid Films 2013, 528, 199–204.

[9]Tabbi Wilberforce, A.G.O. Design of Experiment (DOE) Analysis of 5-Cell Stack Fuel Cell Using Three Bipolar Plate Geometry Design. Sustainability 2020, 12, 4488.

[10] S. Naveenkumar , T. Dharmaprabhakaran, Collection of low-lying cassava by using filtering method.