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Analysis of Flow Field in Proton Exchange Membrane Fuel Cell using COMSOL Software

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Abstract—*Transportation is a field in which there is vast development in the last four to five decades. The present world is powered by the quest for a future alternative technology so that it can be less dependent on the fast depleting fossil fuels. I.C engines use fossil fuel such as natural gas or petroleum products such as gasoline or diesel fuel. The emissions from the I.C engines such as CO_X, SO_X and NO_X has led to the adverse effects on the environment, the various being climate change, acid rain, etc. Additionally the politics and growth economic competition can cause major price rise of fossil fuels. These undeniable causes and the uncompromising standards for emissions from automobiles set by the government have hard-pressed the manufacturers to develop alternate technologies such as fuel cell vehicle, hybrid vehicle, electric vehicle, etc.*

The focus of this paper is that we are going to analyse the flow field channel geometry of hydrogen powered PEMFC, by making a three dimensional computational model and stimulations are done using commercially available COMSOL Multiphysics 5.0 software. The various operating parameters in a fuel cell such as cell temperature, pressure, anode and cathode inlet velocities, etc. which affect the performance of a fuel cell are studied and see how geometry affects the performance the cell.This software is preferred than the traditional experimental way to test a fuel cell due to cost effectiveness and less time period to get the results.

Keywords: *PEMFC, Flow field design, COMSOL Multiphysics 5.0 software.*

1. INTRODUCTION

1.1. Fuel cell

During the past decade, proton exchange membrane fuel cells (PEMFCs) have attracted much attention as an energy conversion technology for automobile and stationary applications with low pollution and high energy efficiency. Fuel cell is a device which converts the electrochemical energy to electric current. Here hydrogen is used as a fuel which can be produced by electrolysis of water or can obtained as a by-product during production of steel and chemical industries hence PEMFC are preferred. Fuel cellFig. [1] has the following parts membrane, anode and cathode electrodes, gas diffusion layer, bipolar plate with flow field in case of a fuel stack.

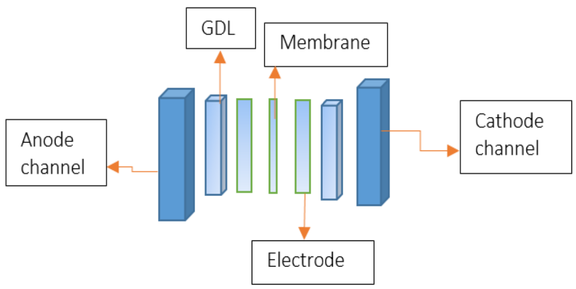


Fig. 1: PEM Fuel cell.

Each fuel cell type has its own unique chemistry, such as different operating temperatures, catalysts, and electrolytes .There are various types of fuel cells Table [1].

Table 1: Different types of fuel cell.

Fuel cell type	Abbreviation	Mobile ion	Operating temperature (°C)
Alkaline	AFC	OH^-	50-200
Proton exchange membrane	PEMFC	H^+	30-100
Direct methanol	DMFC	H^+	20-90
Phosphoric acid	PAFC	H^+	220
Molten carbonate	MCFC	CO_3^{2-}	650
Solid oxide	SOFC	O_2^-	500-1000

1.2. Need for fuel cell

The main need for fuel cell is the emission from gasoline vehicles. Fig. [2] shows how much greenhouse gas is emitted from gasoline vehicles and the emission from future fuel cell. Ref [2]as says the amount of GHG emission from a fuel cell is far more less than the current gasoline vehicle.

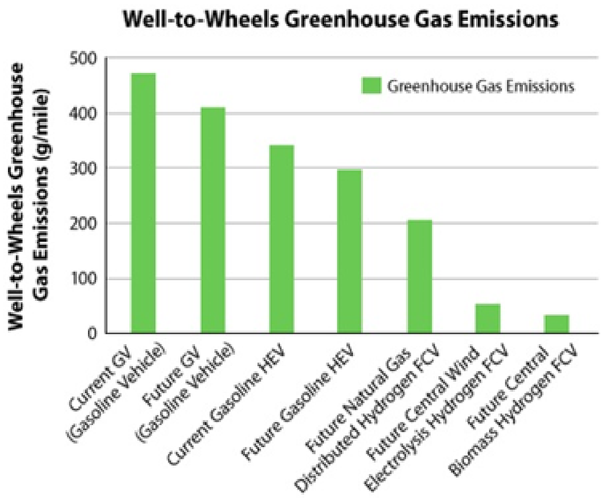


Fig. 2: GHG emissions.

2. COMSOL SOFTWARE

In electrochemical systems, we are concerned with the processes and factors that affect the transport of charge across the interface between chemical phases, for example, between an electronic conductor (an electrode) and an ionic conductor (an electrolyte).This can be analysed experimentally which is slow and costly, so we choose the Comsol software[3] in which a model of a single cell can be modelled and the results can be viewed graphically which is easy and effective in R&D of fuel cell. The different commercially available software are in Table[2].

COMSOL Multiphysicsincludes the COMSOL Desktop graphical user interface (GUI) and a set of predefined user interfaces with associated modelling tools, referred to as physics interfaces, for modelling common applications. The physics-based modules augment the core physics interfaces of COMSOL Multiphysics and provide additional interfaces for electrical, mechanical, fluid flow, and chemical applications.

Table 2: Commercially available software.

MODEL	GC Tool	Easy 5	FEMLAB	MULTIPHYSICS
Origin	ANL	Ricardo	COMSOL	COMSOL
Dimension	0	0	2	3
State				
Transient	A	A	A	A
Steady-state	A	A	A	A
System Boundary				
Cell	NA	NA	A	A
Stack	NA	A	NA	NA
System	A	A	NA	NA
Approach				
Theoretical	NA	A	A	A
Semi-empirical	A	NA	NA	A
Complexity				
Cell/stack	Medium/High	Medium	High	High
Graphical representation	NA	A	A	A
Library	A	A	A	A
Documentation	A	A	A	A

2.1. Working with COMSOL

The steps in the COMSOL Multiphysics software are as follows

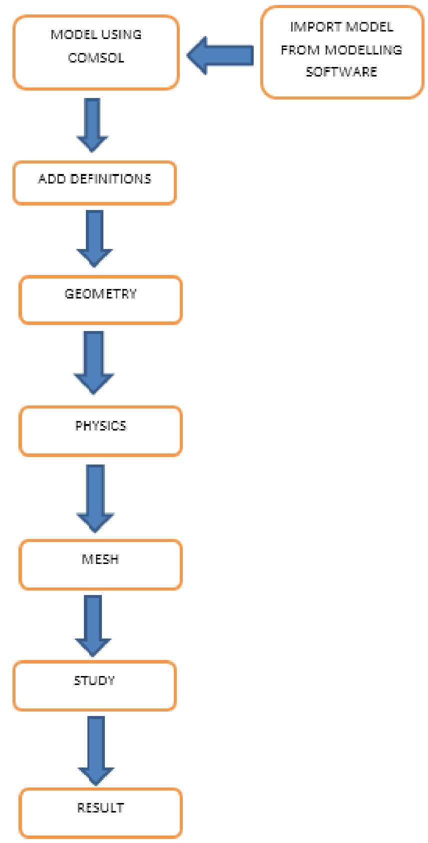


Fig. 3: Work flowin COMSOL.

2.2. Review of Fuel cell models

The various literature models covered for this model are given in table[3].

Table *:* .Review of literature models.

An example of features of some literature fuel cell models covered for this paper

Models	State[a]	System boundary	Studied phenomena
Theoretical approach			
Springer et al.	SS	Fuel cell	Water transport
Bernardi and Verbrugge	SS	Catalyst layer	Cell polarization, water transport and catalyst utilization
Fuller and Newman	SS	Fuel cell	Heat and water management and fuel utilization
Nguyen and White	SS	Gas channels	Heat and water management
Yi and Nguyen	SS	Fuel cell	Heat and water management, species transport
Dannenberg et al.	SS	Fuel cell, along-the-channel	Heat and water management
You and Liu	SS	Cathode catalyst layer	Transport and flow in gas channels and gas diffusers
Boettner et al.	SS	Fuel cell system	System and system component performance and control strategies
Semi-empirical approach			
Kim et al.	SS	Fuel cell	Empirical cell polarization equation
Amphlett et al.	TR	Fuel cell stack	Heat management
Mann et al.	SS	Fuel cell	Generic model

[a] SS: steady-state; TR: transient.

Reference [1] model uses Nernst – Plank equation for species transport, Stefan-Maxwell equation for gas phase transport, Butler – Volmer equation for cell voltage along with conservation equations of energy and mass. A mathematical model of the solid polymer electrolyte fuel cell developed by [5] shows that for practical electrode thickness, results shows that the volume fraction of the cathode available for gas transport must exceed 20% so that we can avoid low current densities and no external water is required for humidification of the membrane since the water produced at the cathode is sufficient .A half-cell model developed by shows that resistance due to oxygen reduction reaction is important for all practical operating current densities[4].The cathode chamber is also pressurized above the anode so that water is forced out of cathode and flooding of the cell is avoided.

3. MODELLING

A model plays an important role in analysing and stimulation of parameters affecting the performance of a fuel cell. The different criteria for fuel cell model are as follows

- Model approach
- State
- System boundary
- Spatial dimension
- Complexity/details
- Time step
- Speed
- Accuracy
- Flexibility
- Source code
- Graphical model
- Library of models, components and thermodynamic properties
- Documentation
- Validation

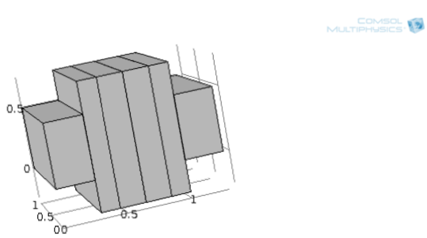


Fig. 4: Fuel cell.

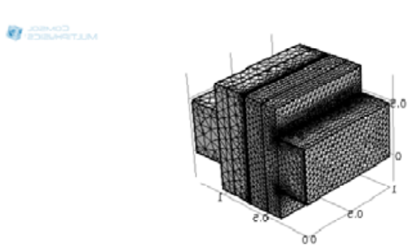


Fig. 5: Model meshed.

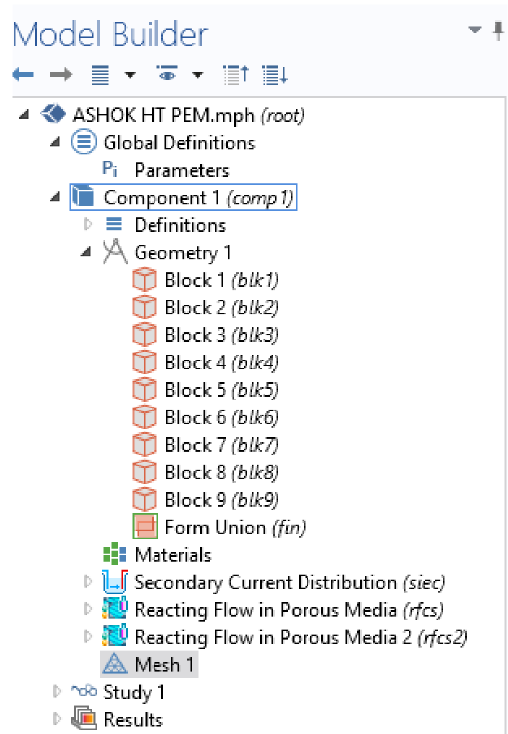
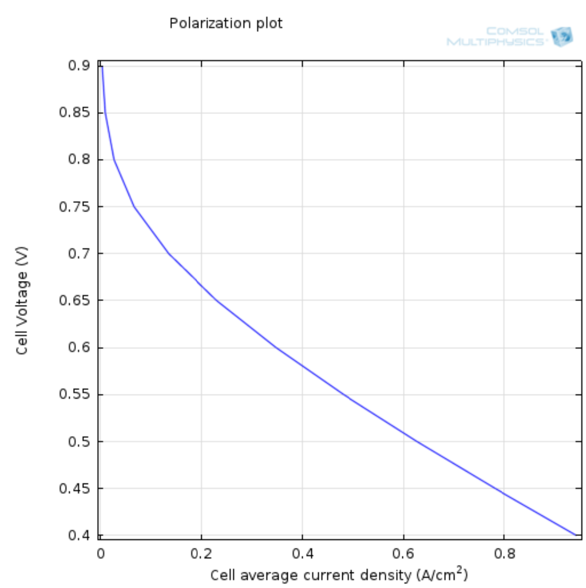


Fig. 6: Sequence in Comsol Multiphysics.

4. RESULTS AND DISCUSSION

The polarization curve is a curve between the cell voltage (V) on Y-axis and cell average current density (A) on X-axis.



5. CONCLUSION

The above polarization curve is for the temperature of 453K of a fuel cell. In future we can use this software for analysing the performance of fuel cell for low as well as high temperature.

6. ACKNOWLEDGEMENTS

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