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ANALYSIS OF A LITHIUM-ION BATTERY COOLING SYSTEM FOR ELECTRIC VEHICLES USING A PHASE-CHANGE MATERIAL AND HEAT PIPES

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Abstract *A low cost bipolar plate materials with a high fuel cell performance is important for the establishment of Proton Exchange Membrane (PEM) fuel cells into the competitive world market. In this research, the effect of different bipolar plates material such as Aluminum (Al) and Copper (Cu),of a single stack of proton exchange membrane (PEM) fuel cells was investigated both numerically and experimentally. 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.*

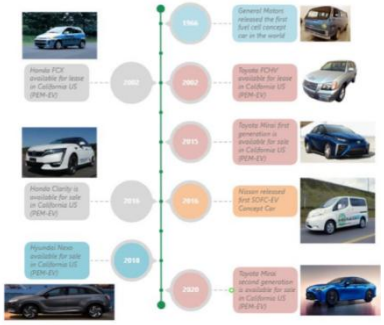
Lithium-ion power battery has become one of the main power sources for electric vehicles and hybrid electric vehicles because of superior performance compared with other power sources. In order to ensure the safety and improve the performance, the maximum operating temperature and local temperature difference of batteries must be maintained in an appropriate range.In this paper, the modeling in CREO parametric software and analysis done in ANSYS. The model designed with different type of heat pipe shapes and analyzes the heat pipe with different mass flow inlets (30, 40, 50, L/min). In this thesis CFD analysis to determine the pressure, velocity, heat transfer coefficient, mass flow rate and heat transfer rate for the different designs of heat pipe and different mass flow inlets. In this thesis the thermal analysis to determine the temperature distribution and heat flux for two types of phase change materials (RT50 and Li Fe PO4).

1. Introduction

Fuel cells are devices that produce electricity through electrochemical reactions.Energy resources can be divided into three major categories: hydrocarbons (i.e., fossil fuels), nuclear reactions, and renewable energy (e.g., wind, water, geological sources of steam or hot water, etc.) . Among all of them, hydrocarbons are the most widely used energy source in our daily lives.

1.1 Fuel-Cell Technology and Models

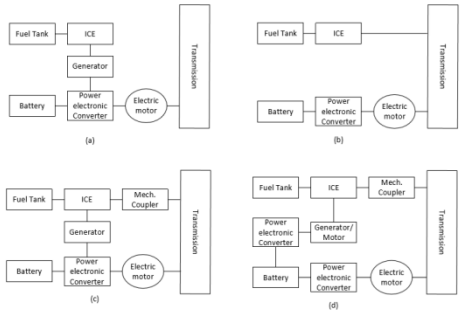
Types of Fuel Cells As the name implies, hydrogen fuel cells use hydrogen as fuel and generate very little pollution (the byproduct is water), and fuel cells do not have sunlight or wind velocity constraints compared to solar or wind power; therefore, there are no geographic limitations. Even in space, NASA used fuel cells to power the space shuttle about 70 years ago, and they used the byproduct—water—to supply drinking water for the crew and conduct cabin air humidification. Hydrogen fuel cells come in various types, each tailored for specific applications and operational conditions. There are six main types of fuel cells, and they are classified by the types of electrolytes used. Each operates at different temperature ranges and uses different fuels. They all have their own advantages and unique applications. Understanding these different types is crucial for evaluating their advantages, limitations, and potential applications in the field of hydrogen fuel-cell technology and electric vehicle applications. For example, fuel cells that operate at higher temperatures are impractical in FC-EV applications because maintaining these temperatures in a moving vehicle requires complex and extensive thermal management systems, which would increase the vehicle weight while reducing the overall efficiency.



Fuel-cell vehicles' key milestones up to the year 2024

1.2 Hybrid Electric Vehicles (HEVs)

Hybrid electric vehicles became popular with the Toyota Prius, first introduced in 1997, and many generations have evolved. They combine an internal combustion engine with an electric motor and a small battery pack. They have a more complex system than ICEs or BEVs. Figure 8 shows the different architectural designs in HEVs. Table 3 shows key parameters when comparing ICEs, EVs, HEVs, and FC-EVs, where MPGe is "miles per gallon of gasoline-equivalent". The EPA calculates that 33.7 kWh (121 MJ) is equivalent to one gallon of gas



Various architectures of an HEV. (a) Series hybrid (b) Parallel hybrid (c) Series–parallel hybrid (d) Complex hybrid.

Adapted from HE Hybrid Electrical Vehicles (HEV) and Electrical Vehicles (EV) become more popular in recent days due to various factors like greenhouse gases and exhausting fossil fuels. The battery becomes the most important source for Energy Storage System (ESS) in Hybrid Electrical Vehicles (HEV) and Electrical Vehicles (EV). Among the battery Energy storage system lithium based battery have high voltage, good energy density, low self discharge rate of good stability as become the major source for Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) [1]. In conventionally HEV and EV uses Nickel Metal Hydride (N-MH) and Lead acid batteries has storage system which has minimum energy density and reasonable price. However Lithium battery has high calendar life and high energy density is preferred for HEV and EV vehicle which is readily available in the market [2]. Although Lithium Ion battery have very high performance sensitive towards the thermal problem like continuous charging, discharging working under high temperature become the major impact lead to cell degradation affect Lithium battery life and performance of the battery. The battery management system investigates the important parameters like state of charge, state of health of battery. An Effective thermal management system must to maintain in battery pack of HEV and EV system that could maintain the operating temperature in the lithium battery for batter State of charge (SOC) and improved calendar life of Lithium-Ion batteries [3].

Various thermal management systems for battery pack are their like air and liquid are used as cooling medium. Finite element analysis of lithium ion battery for Electric vehicle application [4] propose a new material for cathode of Lithium– Ion battery a recently introduced Orthosilicate Compound Li2MSiO4 is used as cathode material. It is the cheapest material with high initial charge profile and improved ionic conductivity and has better temperature withstand capacity [5]. The main purpose of the study is carried out the thermal flow analysis to investigate the temperature distribution at the state of charge and discharge condition of the Lithium Ion battery module used for an EV.

2. LITERATURE REVIEWS

Tabbietal.[1]proposemodificationstosomeconventionaldesignofbipolarlateflow design of PEM fuel cells. The investigation was conducted by using computational fluid dynamics (CFD) Ansys CFX to study various designs and their effect on pressure dropsby varying the flow rate for each design modeled. They concluded that modifications of existing conventional designs, using a method that is similar to a diesel injection system, did reduce the pressure drop, which will contribute to the overall improvement of PEM fuel cell performance.

Hong et al. [2] studied the challenges facing uniform flow distribution in fuel cell applications. They present a novel method for uniform flow field channel distribution, for which multiple levels of flow channel bifurcations were examined, to distribute flow uniformly from n into 2n levels flow field channels of bifurcation. CFD fluent software was used to study flow channel bifurcation dimensions and structure effects on the uniformity of flow distribution in the fuel cell. They found out that the length of flow channel against the width, in the straight part after a 90-degree turn, does have a crucial effect on the uniformity of flow distribution. Additionally, the curvature of flow channels at a 90 degree turning area

and round corners are essential for flow field channel uniformity as a result of the low-pressure loss. Lung and leaf design flow field channels were proposed by Jason et al. [12]. This bio-inspired design was evaluated using numerical simulation (COSMOL Multiphysics 3.4) to study the effect on fuel cell performance. The maximum operating conditions for both designs was a cell temperature between 65 ◦C and 75 ◦C, with the backpressure of 2 atm and 100% relative humidity. Under these cell operating conditions, it was seen that there was a notable improvement in the pressure drop, peak power density, and overall performance than the conventional flow channels.

Mohammad and Behzad [3] examine the effects of flow field channels dimensions on fuel cell performance. The simulation result demonstrated that if the channel width is increased, then the limiting current density will improve. A CFD investigation on a PEM fuel cell was conducted in order to examine the performance of three different conventional flow channels modify to tubular plates by Sierra et al. [4]. The fluid dynamics equation solution, CFD electrochemical model and different variables of distribution contours were obtained. The distribution contours permit local analysis of transport occurrence, which shows that the tubulardesigndisplaymoreuniformityindistributionsof oxygenconcentration,hydrogen, current density, and pressure than a conventional flow channels design. It was concluded that the tubular design that has straight channels shows the least pressure drop among the channels.

3. SELECTION OF NANO MATERIAL

The choice of advanced material for cathode is preferred to reduce the thermal issue problem in Li battery. The cathode materials are developed with high energy density, safety, durability, less cost, and high calendar life. In the study of cathode material in recently developed materials are Olivine structure (LiMPo4) (LiFePo4), Orthosilicate structure (Li2MSiO4) are the advanced developed nano materials. In this analysis Orthosilicate structure (Li2MSiO4) has been used as the cathode material for the optimization of thermal issue problem in Li batteries.

Orthosilicates Li2MSiO4 (M = Fe, Mn, Co) has been selected as the novel Cathode material for Lithium Ion battery. Li2MSiO4 The reversible capacity of Orthosilicate cathode material greatly benefited from the improved conductivity and was able to achieve 150 mAh/g at 25 8C and 200 mAh/g at 55 8C . To improve the ionic conduction and chemical performance the carbon coating is done and Li2MSiO4 to 209 mAh/g reversible capacity on the first charge

Material	Densi-ty (kg/m 3)	Specifi Heat (J/kgK)	Themal Conduc-tivity (W/mK)	Viscos-ity(kg/ ms)	Thermal Ex-pansion Coefficient (1/K)
Battery	2617	952	3.0	-	-
Fluid	1050e 03	140.8	1.9	78.9	0.00353
Plastic	1401	1051	0.17	-	-

To know the heat generation value and the temperature distribution the battery pack is stimulated using the ANSYS Fluent Software with the thermal parameters. Table 2 shows the radiation of material properties

4. MODELING AND ANALYSIS

CATIA is an acronym for Computer **A**ided **T**hree-dimensional **I**nteractive **A**pplication. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, automobile to consumer products.

CATIA provides the capability to visualize designs in 3D. When it was introduced, this concept was innovative. Since DassaultSystemes did not have an expertise in marketing, they had revenue sharing tie-up with IBM which proved extremely fruitful to both the companies to market CATIA. In the early stages, CATIA was extensively used in the design of the Mirage aircrafts; however the potential of the software soon made it a popular choice in the automotive sector as well. As CATIA was accepted by more and more manufacturing companies, Dassault changed the product classification from CAD / CAM software to Project Lifecycle Management. The company also expanded the scope of the software.

CATIA can be used at different stages of the design - ideate, draw, test and iterate. The software comes with different workbenches (“modules”) that allow CATIA to be used across varied industries – from parts design, surface design and assembly to sheet metal design. CATIA can also be used for CNC.

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CATIA offers many workbenches that can be loosely termed as modules. A few of the important workbenches and their brief functionality description is given below:

Part Design: The most essential workbench needed for solid modeling. This CATIA module makes it possible to design precise 3D mechanical parts with an intuitive and flexible user interface, from sketching in an assembly context to iterative detailed design.

Generative Shape Design: This allows you to quickly model both simple and complex shapes using wireframe and surface features. It provides a large set of tools for creating and editing shape designs. Though not essential, knowledge of Part Design will be very handy in better utilization of this module.

Assembly: The basics of product structure, constraints, and moving assemblies and parts can be learned quickly. This is the workbench that allows connecting all the parts to form a machine or a component.

Fuel cell Geometry Design

The geometry model was built using CATIAV5 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, as shown in Figure 3. After, the grid was exported to ANSYS FLUENT 2024 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.

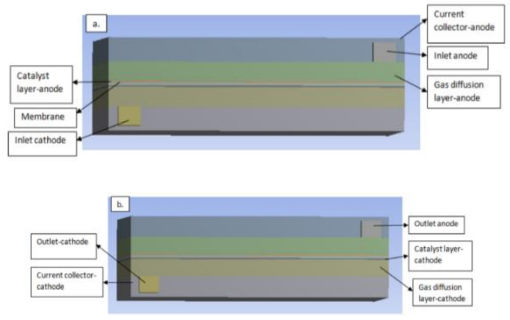
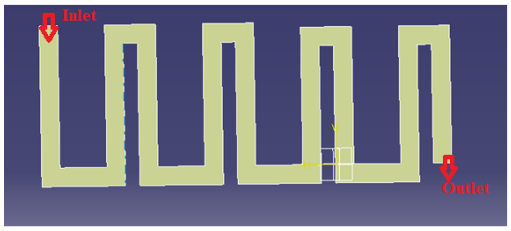
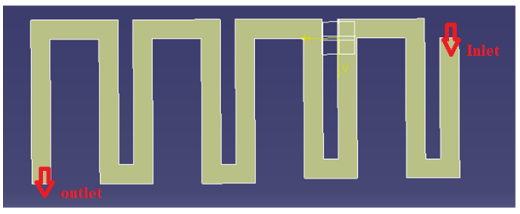


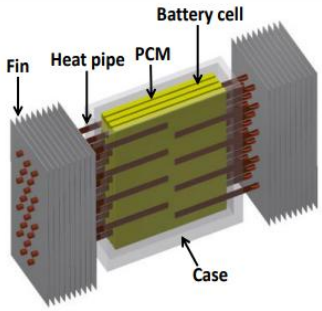
Figure. A three-dimensional view of the single PEM fuel cell and its components. (a) Inlet channel (b) outlet channel.



The anode region



The cathode region



5. CFD ANALYSIS RESULTS

Case 1: straight type

At mass flow rate (L/min)	Pressure (Pa)	Velocity (m/s)	Heat transfer coefficient (w/m2-k)	Mass flow rate (kg/sec)	Heat transfer rate
30	5.33e+06	2.15e+03	4.8e+03	0.000380	2.228
40	9.93e+06	3.00e+03	6.16e+03	0.000748	4.423
50	1.36e+07	3.56e+03	7.08e+03	0.001036	6.12

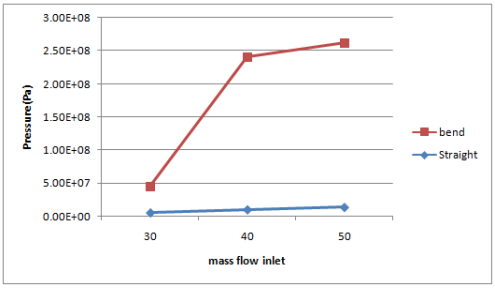
Case 2: Bend type

At mass flow rate (L/min)	Pressure (Pa)	Velocity (m/s)	Heat transfer coefficient (w/m2-k)	Mass flow rate (kg/sec)	Heat transfer rate (w)
30	3.97e+07	3.93e+03	7.24e+03	0.000281	1.666
40	2.31e+08	7.97e+03	1.28e+04	0.001530	9.009
50	2.48e+08	1.12e+04	1.80e+04	00.00150	9.00329

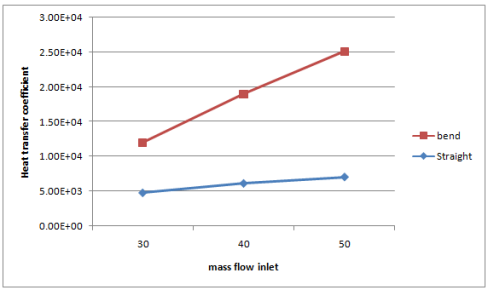
Thermal analysis results tables

Models	Material	Temperature(^{0}C)		Heat flux(w/mm^2)
Design1 (straight heat pipes)	PCM RT50	19.213	80	0.020264
	PCM Li Fe PO4	17.838	80	0.031486
Design 2(bend type heat pipes)	PCM RT50	12.913	80	0.014391
	PCM Li Fe PO4	12.007	80	0.014376

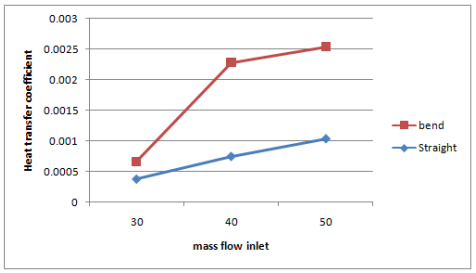
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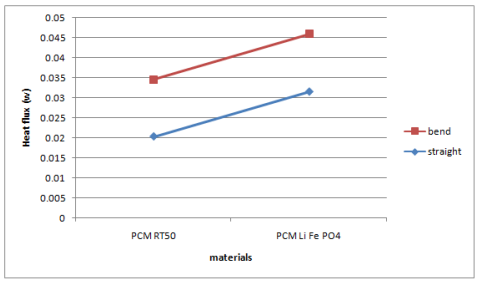
Mass flow inlet Vs pressure



Mass flow inlet VsHeat transfer coefficient



Mass flow inlet Vsoutlet mass flow



Materials Vs heat flux

6. CONCLUSIONS

Lithium-ion power battery has become one of the main power sources for electric vehicles and hybrid electric vehicles because of superior performance compared with other power sources. In this project, the displaying in CREO parametric programs and examination done in ANSYS. The model planned with various sort of intensity pipe shapes and breaks down the intensity pipe with various mass stream gulfs (30, 40 &50L/min).

By Observing the CFD examination mass stream rate, heat move rate, heat move coefficient values are increments by expanding the mass stream channels and intensity move rate more at design2 (Bend type heat pipes). By Observing the Heat examination the intensity Transition esteem is something else for lithium particle phosphate stage change material than RT50 stage change material at design2 (U-Bend heat pipes).

So it tends to be finished up the design2 (U-Bend type heat pipes) is better model for Lithium-Ion battery cooling framework.

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