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ELECTRIC VEHICLE BATTERY THERMAL MANAGEMENT SYSTEM WITH PARAFFIN WAX AND FORCE CONVENTION METHOD

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ABSTRACT
An experimental investigation is performed on an advanced battery thermal management system for emerging electric vehicles. The developed battery thermal management system is a combination of thermoelectric cooling, forced air cooling, and liquid cooling. The liquid coolant has indirect contact with the battery and acts as the medium to remove the heat generated from the battery during operation. Forced air-assisted heat removal is performed from the condenser side of the thermoelectric liquid casing. The purpose of a battery thermal management system (BTMS) is to maintain battery safety and efficient use as well as ensure the battery temperature is within the safe operating range. The traditional air-cooling-based BTMS not only needs extra power, but it can also not meet the demand of new lithium-ion battery (LIB) packs with high energy density, while liquid cooling BTMS requires complex devices to ensure the effect. Therefore, phase change materials (PCMs)-based BTMS is becoming the trend. By using PCMs to absorb heat, the temperature of a battery pack could be kept within the normal operating range for a long time without using any external power. An experimental platform was developed to study thermal phenomena in Li-ion battery pack with PCM material. CFD analysis will be perform to find out temperature of EV battery & PCM during running condition.
Keywords: BTMS, PCM, LIB, CFD Analysis.

I. INTRODUCTION
Energy- saving and environmentally friendly electric drive vehicle(EDV) handover in the request is adding and has further implicit if batteries have farther energy, trip longer, and are less precious. The battery thermal operation system to keep the temperature at an optimal range of 15 ◦ C to 35 ◦ C is essential for lithium- ion(Li- ion) battery packs in electrical vehicles(EVs) and cold-hybrid electrical vehicles(HEVs) to extend continuance and ensure operating safety. During vehicle operation, considerable heat is generated in the battery pack that needs to be rejected. How to remove the generated heat, and keep the temperature outfit has come a challenge because of the high demand of gravimetric and volume energy in EDVs. Several cooling styles have been proposed and excavated. Because of its high energy per unit mass compared to other electrical energy storage methods, lithium-ion batteries are presently employed in most portable consumer gadgets 1 such as mobile phones and laptops. They also feature a high power-to-weight ratio, excellent high-temperature performance, and minimal self-discharge.

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Fig.1. Lithium-ion batteries

Lithium-ion (Li-ion) batteries have risen in prominence in recent decades as a viable power source for a variety of applications, including electric and hybrid cars, power grids, and solar energy storage. Li-ion batteries are widely recommended as a power source in extended driving ranges and quick acceleration because of their high-power density, dependability, and longevity. Li-ion batteries, on the other hand, create heat during quick charge and discharge cycles at high current levels.

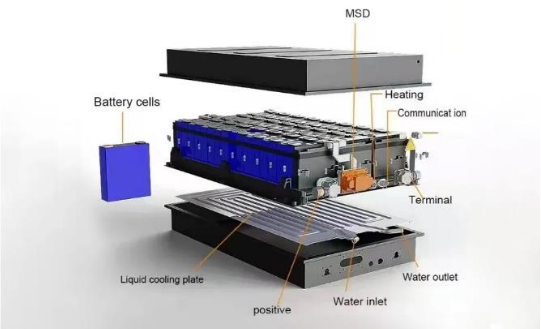

Fig.2. Details of li-ion battery

1.1 Batteries thermal management systems (BTMSs) -

The battery pack management system (BTMS) is crucial for maintaining a safe thermal range for the entire energy battery pack. It should not exceed 20% of the total weight and should not interfere with other parts. BTMS can be passive or active, perpendicular or series, cooling or heating, liquid or air, thermo-electric less hot (TEC), phase-changing material (PCM), or heat pipes (HP). Current popular methods in EDV applications include air cooling, liquid cooling, and fin cooling. Cell-level thermal analysis is used to assess the best cooling method for different applications.

1) **Air cooling method -** Air cooling, a simple method of transferring heat from a battery pack, is used in electric cars like Nissan Leaf. However, safety concerns arise with air-cooled battery packs, especially in hot climates. Liquid cooling is preferred by Tesla. Air-based BTMSs use forced or natural air flow convection, with natural airflow convection supplying air to the battery pack

2) **Liquid cooling method -** Liquid cooling is an efficient and practical method for cooling battery packs, extending their service life. Engineers can optimize thermal management using Multiphysics simulation. Liquid systems can be active or passive, with passive systems using a non-heating radiator. The temperature difference between the battery and surrounding air affects cooling performance, and a radiator with fans can improve performance.

3) **Nanofluid-based -** Liquid coolants like water and ethylene glycol only slightly improve battery cooling efficiency. Adding metal particles can improve thermal conductivity but has maintenance issues and high setup costs. Scientists are developing nanofluids, which combine liquid coolant with nano-sized particles, to increase heat transfer performance and address issues.

4) **Fin cooling method -** Cooling fins increase surface area and heat transfer, but add weight to the pack. Traditionally used in electronics and internal combustion engine vehicles, they have become less popular for cooling electric car batteries due to their weight.

5) **Nanoparticle-enhanced phase change material (NEPCM) -** Nano-enhanced phase change material (NEPCM) is a material that enhances heat conductivity by adding nanoparticles to PCMs. Its properties are influenced by NP morphology, size, and concentration, and PCM properties. A nanofluid with environmental effect has been used to improve heat transmission in PCMs for TES applications.

6) **Nanofluid in the heat pipe -** HPTMS uses heat pipes (HPs) for water cooling in the condenser, but recent research has explored alternative methods like wet cooling with water sprays and air cooling. HPs are used in battery temperature management systems, cooling plates, and PCM. All studies on HPs use water as a working fluid, with a few using nanofluids.

7) **Thermoelectric-based BTMS -** A thermoelectric engine was used for waste heat recovery from ordinary vehicles. Thermal cooling (TEC) systems are popular in power BTM due to their lightweight, small size, low maintenance cost, vibration-free, noiseless, long life, broad temperature range, and high reliability. These systems can heat and cool in both cold and hot conditions.

8) **Hybrid BTMS -** Hybrid BTMS (HBTMS) is a system that combines passive and active methods to enhance heat transfer and control processes. It uses PCMs for temperature uniformity and HPs for high thermal conductivity, enhancing local heat transfer and releasing heat from condensation. For lower thermal loads, forced air can be used as an active cooling system, while liquid cooling is more efficient. However, HBTMSs have drawbacks such as volume, weight, energy consumption, and complexity.

The project present an innovative battery thermal management system (BTMS) for electric vehicles, leveraging the synergies of paraffin wax as a phase-change material (PCM) and forced convection to regulate battery temperature. This research growing for EVs necessitates efficient thermal management solutions to ensure battery performance, safety, and longevity. The project has harnessing the thermal energy storage capabilities of paraffin wax and enhancing heat transfer through forced convection, this BTMS has maintain optimal battery temperatures, mitigate thermal-related risks, and enhance overall vehicle efficiency. This project is an inspiring and challenging approach who are driven to push the limits of thermal management in automotive sector.

II. LITERATURE REVIEW

Hwang et al. [1], This study examines the rearmost developments in BTMS technologies and their strengths and sins. There are four types of BTMS systems in the EV assiduity air- cooled, liquid-cooled, PCMs, and thermo- electric- grounded BTMS. Mongrel systems combine factors of two or further BTMS types to ameliorate cooling performance. Air- cooled systems have low energy conditions, low conservation, and are cheaper to install but not suitable for battery packs with high thermal loads. Liquid- cooled BTMS have better heat transfer portions, advanced specific heat capacities, and uniformed cooling distributions but are more precious, heavier, and bear further conservation. EVs with larger battery packs, long- distance trip, and high thermal loads are best suited for this type. PCM BTMS types can absorb large heat during phase change cycles but have low thermal conductivity and high idle heat capacity only at a narrow temperature range.

Wazeer et al. [2], This review article discusses the use of phase change materials (PCMs) for battery thermal management in electric and hybrid vehicles (EVs and HEVs). PCMs are compared to conventional methods like forced air convection or coolant, and their use confirms uniform temperature distribution with reduced maximum temperatures in the battery, offering potential for mitigating battery life through TMS.

Liu et al. [3], The review evaluates the current application status of PCM and its significant development direction. It suggests that while metal fins could improve PCM thermal conductivity, it would increase system mass and manufacturing costs. However, adding fillers could only increase thermal conductivity within a limited range, and comprehensive understanding of the mechanisms in the preparation stage is necessary.

Misal et al. [4], The thermal battery management system (BTMS) aims to maintain the battery's health and effectiveness while ensuring safe operating range. Conventional air-cooling systems require extra power and cannot meet the high energy density demand for new lithium-ion battery packs. BTMS complex devices are needed for liquid cooling, leading to the use of Phase change materials (PCMs) based on BTMS technology. PCMs absorb heat, allowing the battery pack to maintain its normal operating range without external force. This experimental platform studies thermal phenomena in Li-ion batteries with PCM materials. CFD analysis will be performed to determine battery EV temperature and PCM while operating state.

Shahjalal et al. [5], Electric vehicles (EVs) have shown potential in addressing climate change and carbon reduction, with batteries serving as energy storage devices. However, temperature is a significant threat to EV batteries, especially as fast charging trends increase thermal challenges. This paper discusses various cooling technologies, including air, liquid, PCM, heat pipe, and thermoelectric systems. Air cooling systems are advantageous due to their low weight, cost, and maintenance, but can be problematic due to compressors and fans. Liquid cooling improves air cooling system limitations but also faces issues like indirect contact, extra weight, and rugged construction. Refrigerant-based two-phase cooling can improve performance, while PCM can eliminate liquid cooling problems by replacing pumps. However, PCM is still in academic research and not yet applied to practical EV applications.

Wang et al. [6], This paper discusses the thermal models and thermal management solutions for lithium-ion batteries used in hybrid electric vehicles (HEVs) and electric vehicles (EVs). The battery thermal model can be thermal-electrochemical coupled or decoupled, depending on heat generation. The fully coupled model uses parameters from the electrochemical model, while the decoupled model uses empirical equations from experimental data. A standalone thermal model may not be accurate for predicting thermal behaviour. Battery thermal management (BTM) is crucial for eliminating thermal impacts, improving temperature uniformity, prolonging battery lifespan, and enhancing safety. Factors such as temperature effects, heat sources, and temperature control should be considered for effective thermal management.

Ahmed et al. [7], The battery pack simulation with forced convection without the PCM model yields better results, as it is easy to design with a small fan, making it a suitable choice for formula electric cars. However, due to the high cost of Phase change materials, it is not recommended to use the PCM model.

Zhou et al. [8], This section discusses the use of active and unresistant cooling styles for managing lithium- ion batteries' thermal performance. Liquid provides ideal cooling performance, while phase change material (PCM) improves temperature uniformity. still, supplementary mechanisms are demanded to dissipate heat effectively. A cold-blooded liquid- cooled plate, a mixed system with phase change material bedded in the cooling plate, can ameliorate temperature uniformity. This heating result mitigates temperature loss in batteries and offers advantages over traditional cooling plates. The new liquid- cooled plate (LCP) bedded with PCM is 36 lighter than traditional aluminium LCP, demonstrating the eventuality of these styles in perfecting battery performance.

Fu et al. [9], Battery heat generation models include electrochemical thermal and electrical- thermal models, with multidimensional models being more extensively delved for comprehensive descriptions. Air cooling BTMS is suitable for small battery systems due to its provident manufacturing cost and compact structure. Recent focus on air- cooling systems has been on optimizing battery pack design, perfecting cooling channels, and adding thermal conductivity accoutrements. Trends in developing air- cooling systems include perfecting cooling effectiveness, reducing power consumption, and adding high- temperature rigidity to address changeable battery failure and thermal raw.

Moussa EL IDI et al. [10], This paper examines the thermal gets of a Li- ion cell, specifically spherical 18650 cells, generally used in electric vehicles. An experimental platform was developed at CERTES Lab to study the battery's thermal teste at cell scale. The thing was to propose a new battery- to- essence- system (BTMS) that ensures an optimal operating temperature of 25 ◦ C for 1C charge/ discharge cycles. The study set up that axial thermal conductivity is more important than radial one, and the PCM can absorb heat generated by the cell in idle form during solid-liquid phase changes.

Wang et al. [11], This paper discusses the significance of thermal operation systems in electric vehicle operation, fastening on the choice of system grounded on cooling capacity, APP script, and cost. It evaluates the advantages and disadvantages of different thermal operation systems under different cooling capacities using maximum temperature difference and maximum battery temperature as evaluation indicators. Thermal operation systems can be divided into four corridor air, liquid, PCM- grounded, and mongrel. The paper simplifies factors affecting heat dispersion intensity and compares new cooling models with former models, recapitulating their characteristics and advantages. Secondary factors are ignored.

Han et al. [12], The study synthesizes and analyzes colorful cooling systems for electric vehicle batteries, including Air Cooling, Liquid Cooling, Refrigerant Direct Cooling, Phase Change Material Cooling, Thermoelectric Cooling, Heat Pipe Cooling, and mongrel Cooling. The results punctuate the advantages and disadvantages of these systems and offer implicit ideas for unborn exploration in the field of battery cooling for electric vehicles. Nguyen Tien Han et al. [12], The study synthesizes and analyses various cooling systems for electric vehicle batteries, including Air Cooling, Liquid Cooling, Refrigerant Direct Cooling, Phase Change Material Cooling, Thermoelectric Cooling, Heat Pipe Cooling, and Hybrid Cooling. The results highlight the advantages and disadvantages of these systems and offer potential ideas for future research in the field of battery cooling for electric vehicles.

III. PROBLEM STATEMENT

EV Batteries have specific operating ranges, which are critical for the battery life and performance. They are designed to operate at ambient temperature, which is between 68°F and 77°F (20°C and 25°C). A better control over the battery temperature improves their performance and life.

- During operation, they can withstand temperature between -22°F and 140°F (-30°C and 50°C)
- During recharges, they can withstand temperatures between 32°F and 122°F (0°C and 50°C)

Batteries generate a lot of heat during operation and their temperature must be brought down within operating ranges. At high temperatures (between 158°F and 212°F, or 70°C and 100°C), thermal runaways can occur, causing a chain reaction that destroys the battery pack. During fast charges, batteries must be cooled down. This is because the high current going into the battery produces excess heat that must be extracted to preserve the high charging rate and not overheat the battery.

IV. OBJECTIVES

- To improve performance of Battery by optimizing battery temperature by using PCM
- Implement and test the cooling system on an electric vehicle to ensure optimal battery temperature management.
- Improve safety by preventing thermal runaway and the risk of battery fires.
- Thermal and CFD analysis of concept battery model using nanofluid
- Manufacturing of concept battery model and testing of CFD results.

V. METHODOLOGY

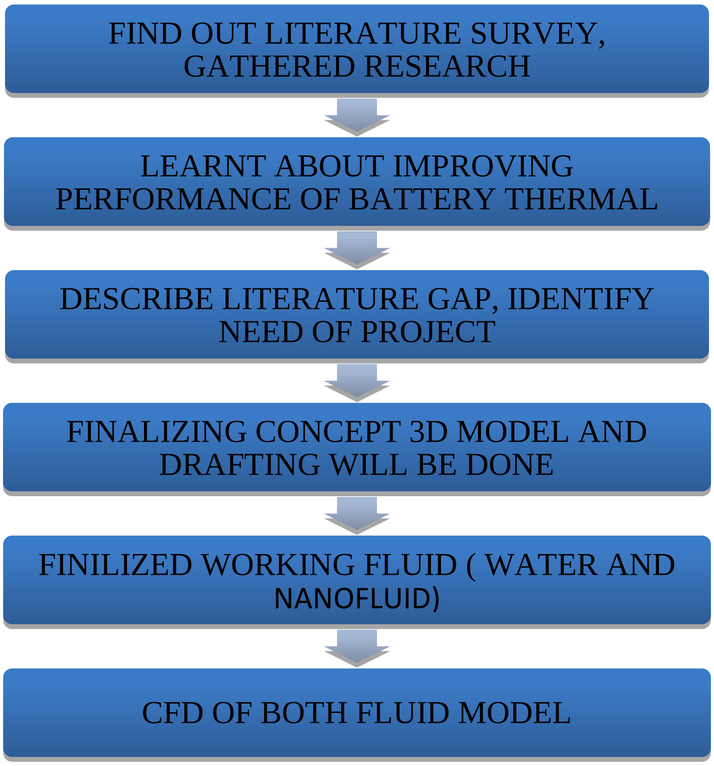

Fig.3. Methodology

VI. DESIGN OF BATTERY COOLING

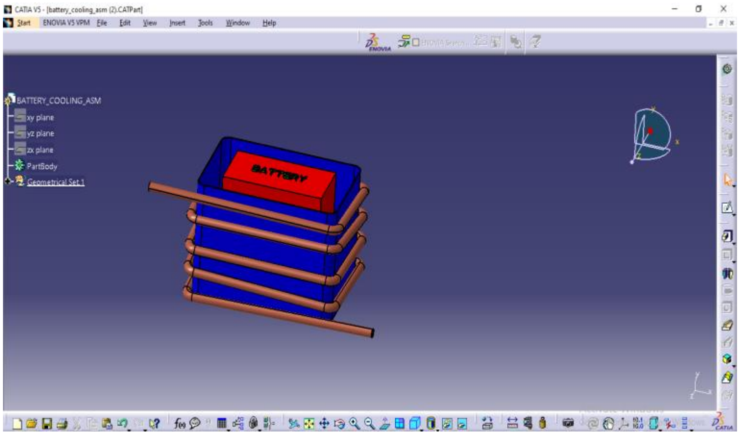

Fig.4.3D MODEL IN CATIA

6.1 Drafting

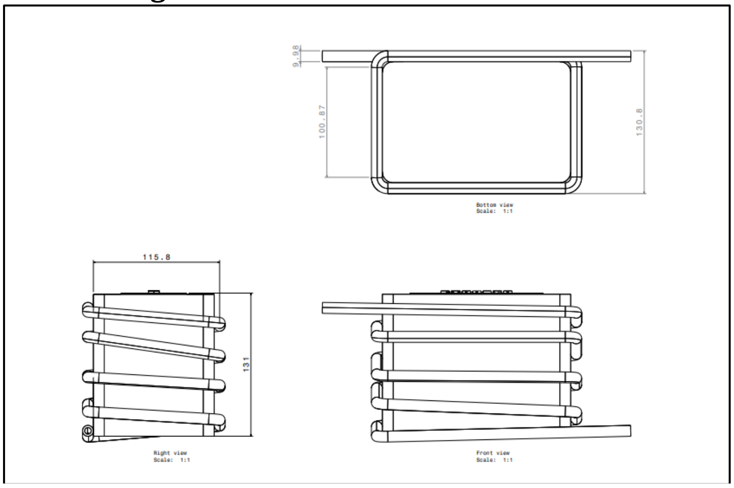

Fig.5.Drafting

6.2 Steady state thermal analysis

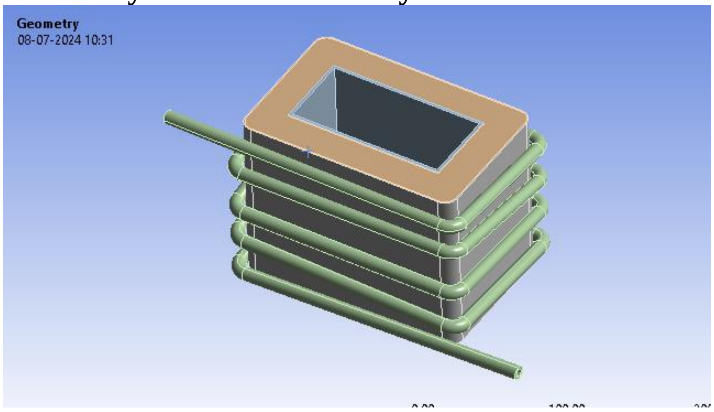

Fig.6.Geametry

6.3 Material

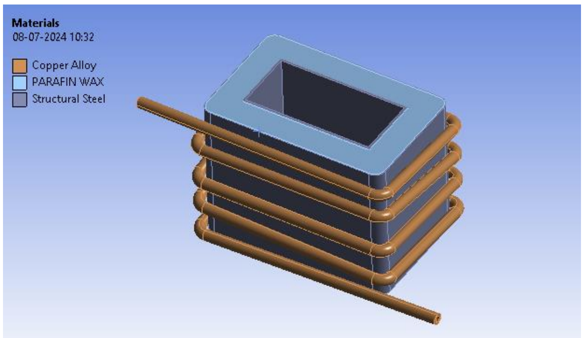

Fig.7.Material

6.4 Meshing

As the main link of finite element analysis, grid division can best reflect the idea of finite element. The quality of the web site not only affects the efficiency of model analysis, but also directly affects the accuracy of analysis results. Therefore, according to the existing hardware, without affecting the accuracy of the calculation results, the method of dividing the mesh can be appropriately selected to save calculation time.

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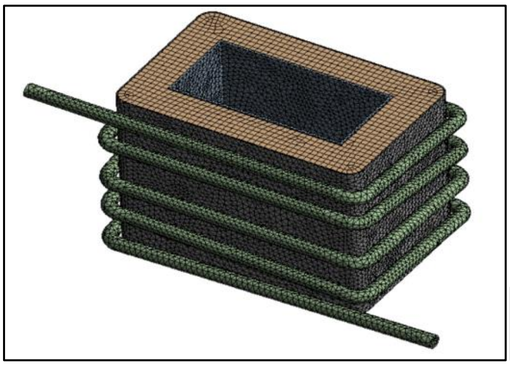

Statistics	
Nodes	285767
Elements	111416

Fig.8.Meshing

6.5 Thermal Boundary Condition

At high temperatures (between 158°F and 212°F, or 70°C and 100°C), thermal runaways can occur, causing a chain reaction that destroys the battery pack. So, temperature of battery was 70°C and flow was convection.

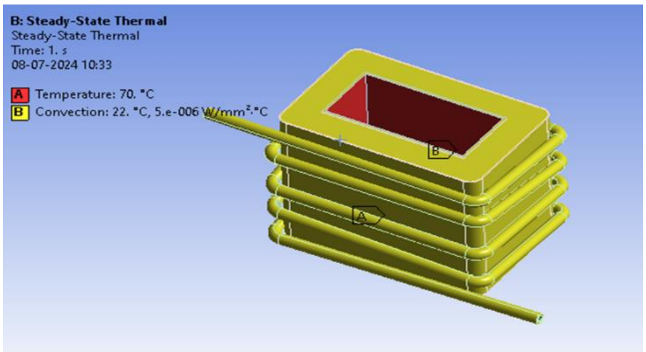

Fig.9.Thermal Boundary condition

VII. RESULTS OF THERMAL BOUNDARY CONDITIONS

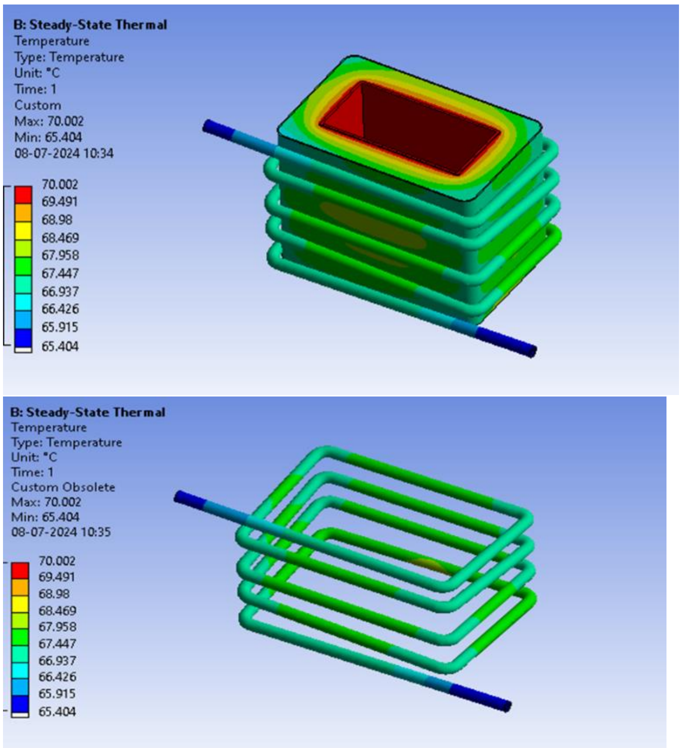

Fig.10.Result

Average temperature of copper pipe wall was 67 ^{0}C.

VIII. COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to dissect and break problems that involve fluid overflows. CFD is now honoured to be a part of the computer- backed engineering (CAE) diapason of tools used considerably moment in all diligence, and its approach to modelling fluid inflow marvels allows outfit contrivers and specialized judges to have the power of a virtual wind lair on their desktop computer.

8.1 CFD Procedure

There are five steps are used to solve the problem in CFD. They are:

(a) Geometry Development

(b) Mesh Generation

(c) Specification of flow condition

(d) Calculation and numerical solution

(e) Results

8.2 CFD analysis of water

1. Geometry

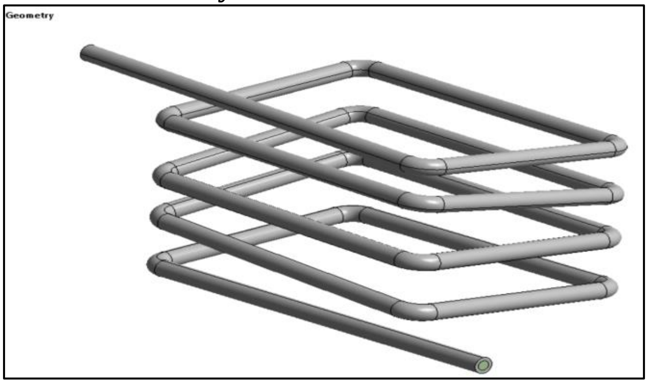

Fig.11. Geometry

2. Meshing

Meshing has been done using ANSYS meshing tool. Meshing of the geometry is as shown in figures

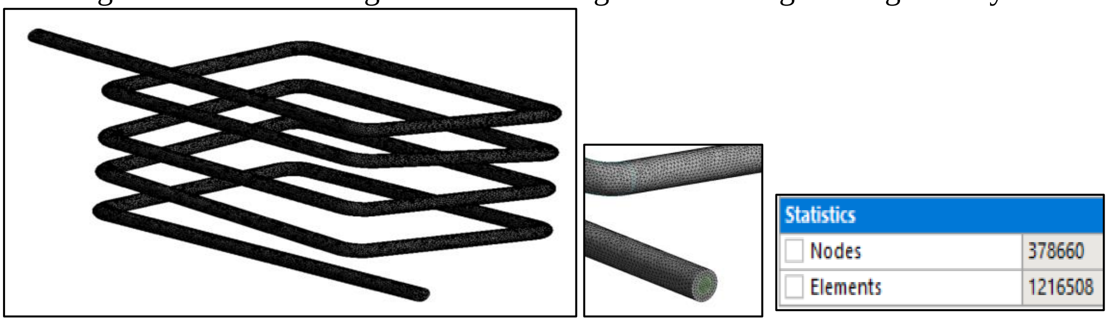

Fig.12. Meshing

After meshing of geometry, we get 378660 nodes and 1216508 elements.

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3. Nomenclature

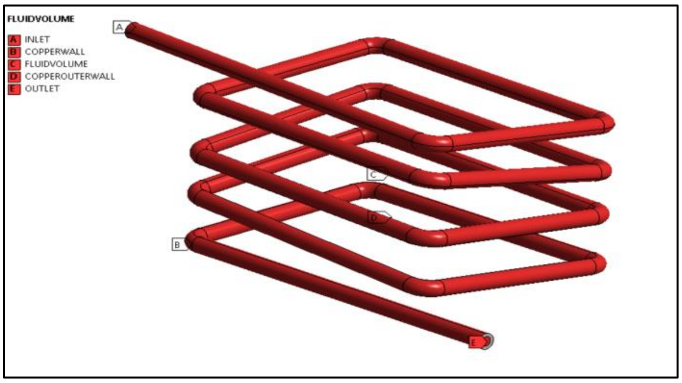

Fig.13.Nomenclature

4. Boundary conditions

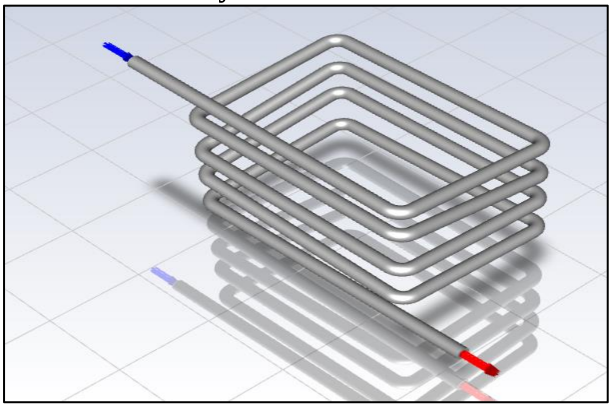

Fig.14.Boundary Conditions

IX. CALCULATIONS

v = Flow velocity
Q = Volumetric flow rate
A = Cross-sectional area

$$v = \frac{Q}{A}$$

Q = Volumetric flow rate = 120 L/H

A = Cross-sectional area

$$A = \pi r^2$$

$$A = \pi \times 2.5^2$$

$$A = 19.63495$$

$$v = \frac{Q}{A}$$

$$v = \frac{120}{19.63495}$$

$$v = 1.69808117 \frac{m}{s}$$

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Boundary condition of inlet velocity

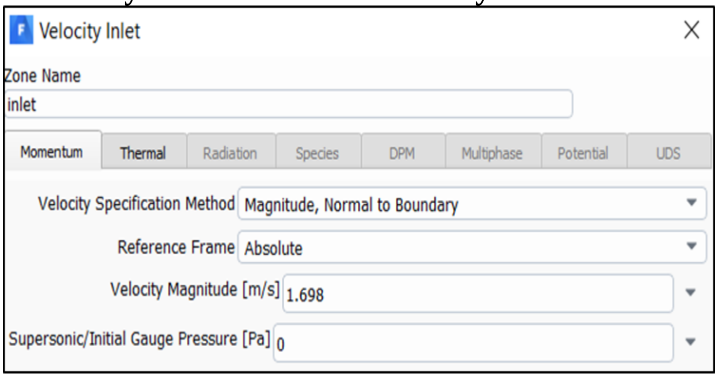

Fig.15.Boundary Condition of inlet velocity

Thermal properties of water

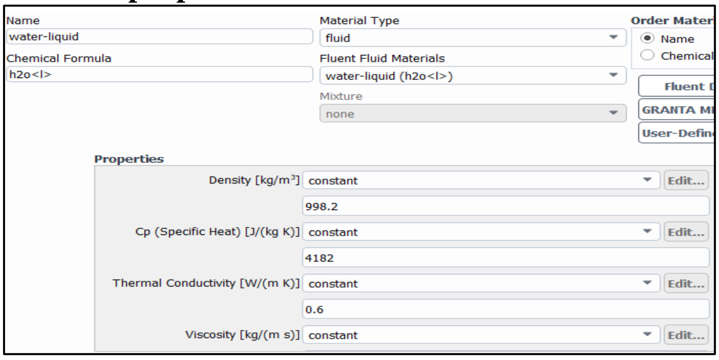

Fig.16. Thermal properties of water

Inlet temperature of water

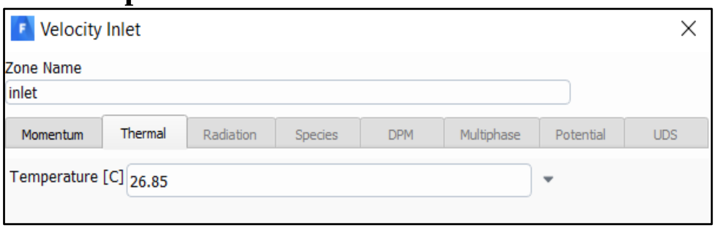

Fig.17. Inlet temperature of water

Wall temperature of copper wall pipe

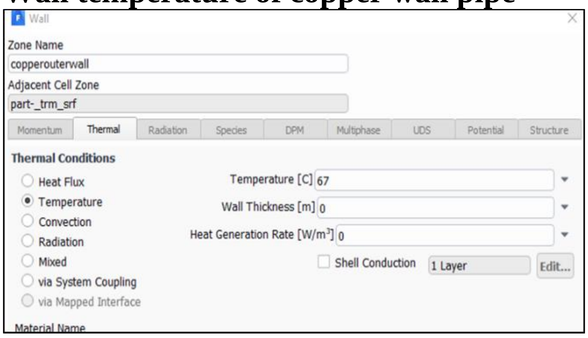

Fig.18. Wall temperature of copper wall pipe

X. RESULTS OF CFD ANALYSIS

10.1 Velocity contour

Velocity contour plots showing that when cold water fluid enters the copper pipe and passing through the complete pipe

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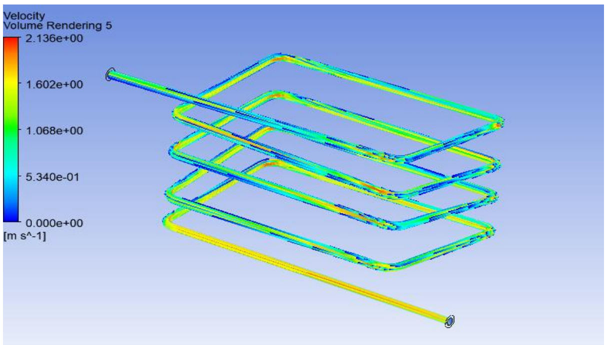

Fig.19.Velocity - Volume Renderings for water
Maximum Haste of water at outlet of pipe was2.136 m/ s

10.2 Temperature Contour

Temperature figure as shown in figure shows how temperature varying in different zones

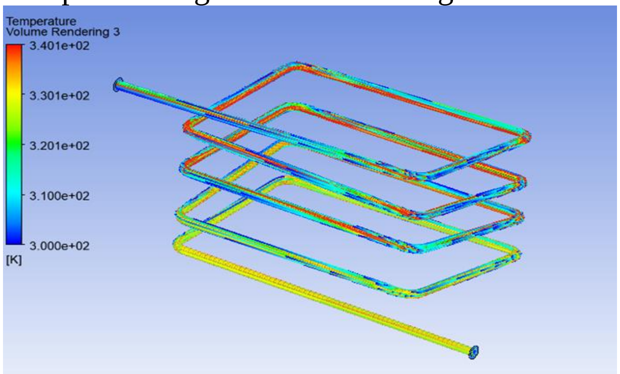

Fig.20. Temperature- Volume Renderings for water
Maximum temperature of water at outlet of pipe was 340K

10.3 Pressure Contour

Figure shows that pressure is gradually increasing as fluid flows through the pipe

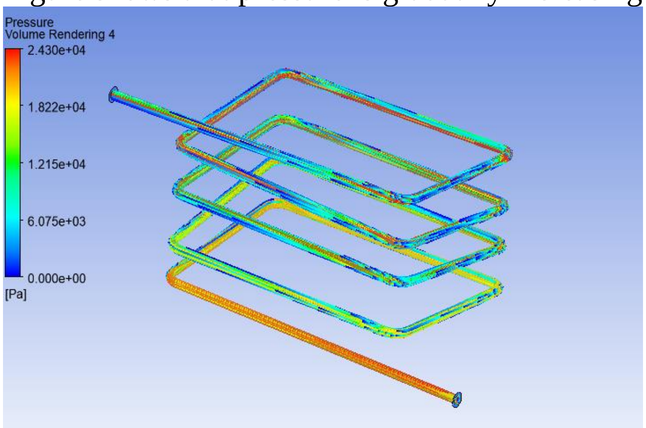

Fig.21.Pressure - Volume Renderings for water
Maximum Pressure of water at outlet of pipe was 2.430 e+04 Pa

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10.4 Temperature at outlet of copper tube

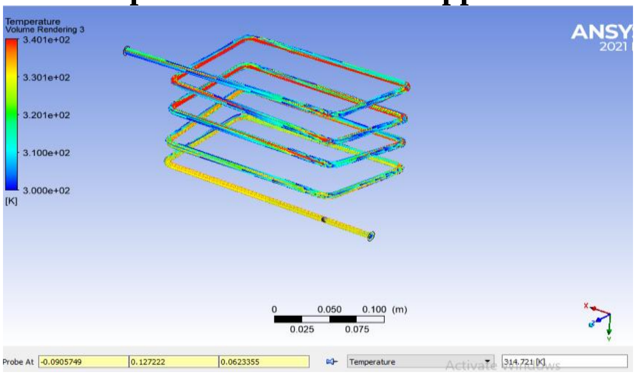

Fig.22.Temperature at outlet of copper tube

10.5 CFD analysis of Cu-water nanofluid

Copper oxide (CuO) water nanofluids are made by dispersing copper oxide nanoparticles into water. The nanofluids can have improved thermal conductivity and other properties compared to water alone. Thermal properties of copper oxide (CuO) water nanofluids for 2 percentage weight fractions

		k	μ	ρ	C_p	u_m
$\varphi = 2\%$	Al_2O_3-water	1.6525	0.001004	1056	3921	0.57
	CuO-water	1.5790	0.001142	1103	3700	0.54
	TiO_2-water	1.4937	0.001394	1060	3906	0.49
	Cu-water	1.4310	0.001690	1145	3629	0.44
	Ag-water	1.3725	0.001966	1187	3488	0.41
	Diamond-water	1.6482	0.001013	1047	3941	0.57

Fig.23. CFD Analysis of Cuo-water Nanofluid

The performance evaluation of the battery cooling system was performed using pure water, CuO-water nanofluid (2% weight fractions) with paraffin wax as a phase change material

10.6 CuO-water nanofluid

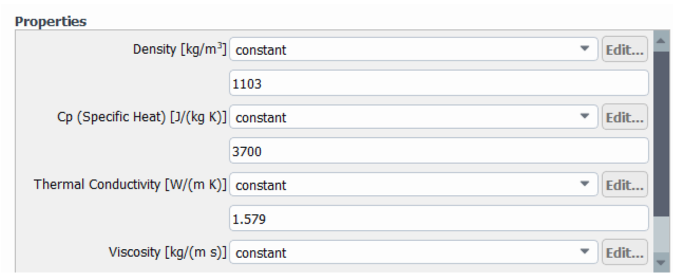

Fig.24.Result

Results - CuO-water nanofluid

10.7 Velocity contour

Velocity contour plots showing that when cold copper oxide (CuO) water nanofluids enters the copper pipe and passing through the complete pipe

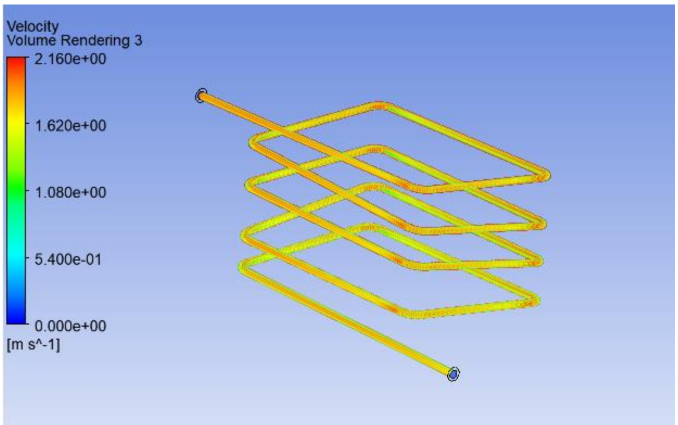

Fig.25. Velocity - Volume Renderings for copper oxide (CuO) water nanofluids
Maximum velocity of copper oxide (CuO) water nanofluids at outlet of pipe was 2.160 m/s

10.8 Temperature contour

Temperature contour as shown in figure shows how temperature varying in different zones.

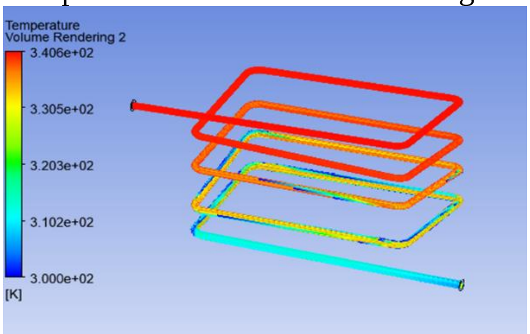

Fig.26.Temperature- Volume Renderings for copper oxide (CuO) water nanofluids
Maximum temperature of copper oxide (CuO) water nanofluids at outlet of pipe was 340K.

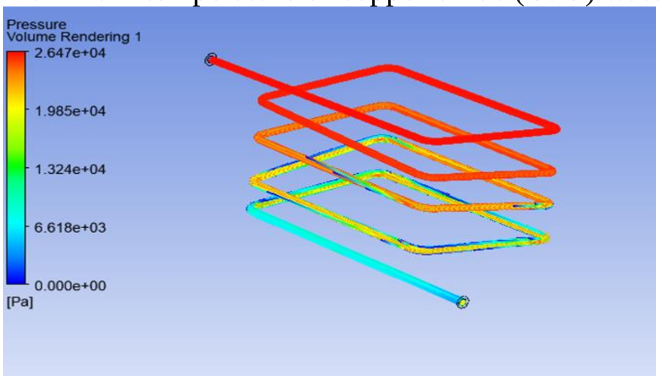

Fig.27.Pressure - Volume Renderings for copper oxide (CuO) water nanofluids Maximum Pressure of copper oxide (CuO) water nanofluids at outlet of pipe was 2.647 e+04 Pa.

10.9 Temperature at outlet of copper tube

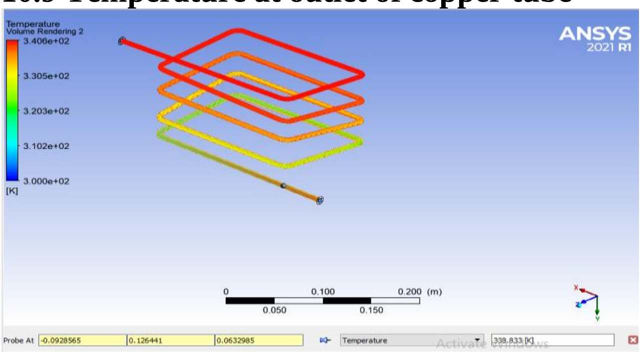

Fig.28.Temperature at outlet of copper tube

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Temperature of copper oxide (CuO) water nanofluids at probe indicate on pipe was 338.833 K or 65.7 °C.

Type of fluid	Temperature of battery °C	Temperature of fluid at inlet of copper pipe	Temperature of fluid at outlet of copper pipe (CFD)	Temperature of fluid at outlet of copper pipe (Experimental)
Water	70°C	26.85°C	41.5°C	40.5°C
Cuo-water nanofluid	70°C	26.85°C	65.7 °C	64.5 °C

Table 1. Results

For water fluid ΔT =T1 -T2=26.85-41.5=14.65 °C **and** Cuo- water nanofluidΔT was 38.85 °C

For water fluid,

Temperature of battery 70°C - ΔT= 70°C-14.65°C=55.35°C, this temperature not a safe for battery.

For Cuo-water nanofluid,

Temperature of battery 70°C - ΔT= 70°C-38.85°C=31.15°C, safe condition for battery.

XI. Experimental set up:

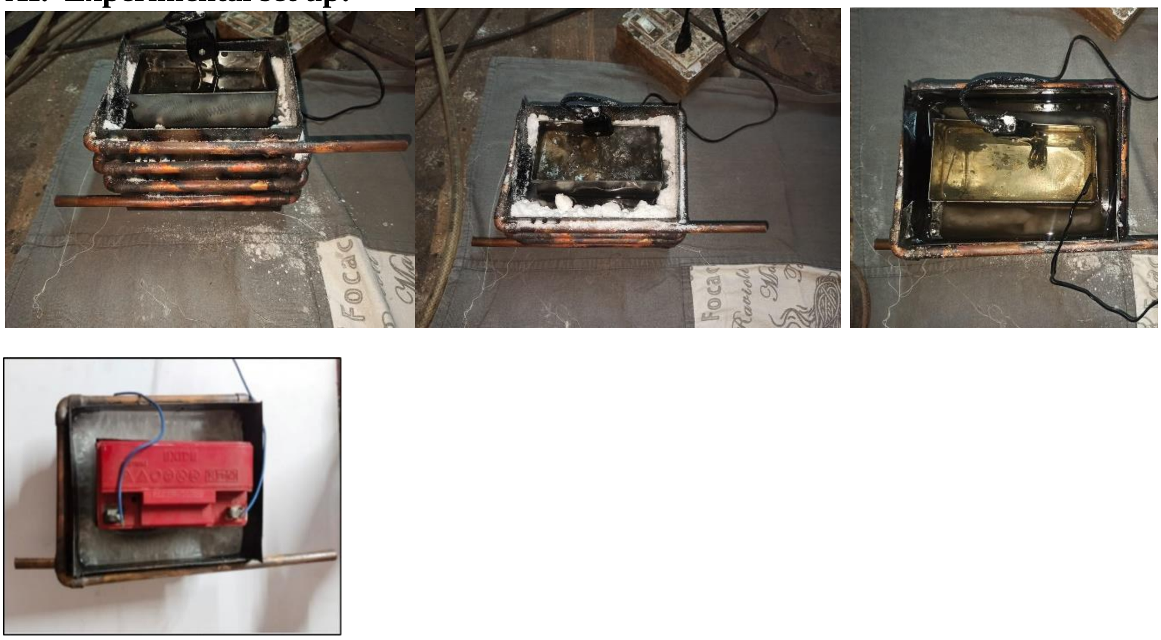

Fig.29 experimental setup

XII. CONCLUSION

By combining the latent heat storage capabilities of paraffin wax with the efficient heat transfer provided by forced convection, this hybrid system effectively mitigates temperature fluctuations within the battery pack. The results demonstrated a significant reduction in peak battery temperature, improved temperature uniformity, and extended battery life compared to traditional cooling methods. From CFD analysis of test rig model it concludes that Cuo- water nanofluid has maximum heat carrying capacity than water fluid

Cuo- water nanofluid and paraffin wax maintaining optimal operating temperatures through effective thermal management significantly extends battery lifespan and reduces capacity fade.

Overall, the integration of paraffin wax and forced convection in EV battery thermal management systems represents a substantial step forward in achieving safe, efficient, and long-lasting electric vehicles.

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