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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:

Lithium-ion power batteries have emerged as primary power sources for electric vehicles and hybrid electric vehicles due to their superior performance compared to other alternatives. Ensuring safety and optimizing performance require maintaining battery temperatures within appropriate ranges. Temperature significantly affects the storage and discharge capacity of batteries, with electrode structure, including thickness, particle size, and porosity, influencing heat generation. This paper presents a modeling and analysis approach conducted using CREO Parametric software and ANSYS.

Different heat pipe shapes are modeled and analyzed, along with variations in mass flow inlets (30, 40, 50 L/min). Computational Fluid Dynamics (CFD) analysis is employed to determine pressure, velocity, heat transfer coefficient, mass flow rate, and heat transfer rate for various heat pipe designs and mass flow inlets. Additionally, thermal analysis assesses temperature distribution and heat flux for two types of phase change materials (RT50 & RT35).

Keywords: CFD, Mass flow rate, CREO, Lithium-ion battery, PCM.

1. **Introduction**:

Lithium-ion batteries (LIBs) have garnered significant attention for traction applications due to their high energy density, power capabilities, and low atomic mass. The graph presented in Figure X illustrates the energy density comparison among various secondary batteries. The energy storage

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requirements for Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs) exceed those for Hybrid Electric Vehicles (HEVs) to enable extended all-electric range travel. LIBs have emerged as promising solutions for environmentally friendly transportation, including HEVs, PHEVs, and EVs. These batteries consist of cathodes, anodes, separators, and electrolytes, operating through an "extraction/insertion" process and configured in various shapes such as coin, cylindrical, pouch, and prismatic.

Phase Change Materials (PCM):

PCMs are heat-storage materials utilizing latent heat, capable of charging or discharging heat energy through phase changes. They are categorized by composition into organic and inorganic types. Criteria for PCM selection as LiB heat control devices include high latent heat, specific heat, and thermal conductivity, minimal volume change, absence of supercooling, non-toxicity, non-flammability, and cost-effectiveness. Paraffin wax, an organic PCM, satisfies many of these criteria and comprises straight chain n-alkanes. The material properties used are obtained from the Rubitherm GmbH website product brochure.

2. Literature Review:

Kusekar S.K. et al. (2015) conducted an experiment on the design and development of an electric car, demonstrating the implementation of electric vehicle technology on a small scale. The study highlights the design considerations for an electric car, emphasizing cost-effectiveness and the components required for its construction. It underscores the advantages of electric battery-operated vehicles in terms of low electricity costs and reduced maintenance expenses. Additionally, the study provides insights into calculating the torque required for vehicle movement and understanding chassis design principles, steering systems, caster, camber, drift, acceleration, top speed, and performance tuning.

K. Vignesh et al. (2015) conducted an experiment on the "Design and Fabrication of Free Energy Bicycle," aiming to produce a cheaper and more effective system than existing ones. Their approach involved fitting a dynamo onto the bicycle, in contact with the rear wheel. The dynamo, connected to the battery terminals, recharged the battery while in motion, with the motor linked to the rear wheel via a main shaft to transmit power.

Awash Tekle et al. (2014) investigated "Renewable Energy Use for Continuous Electric Vehicle Battery Charging Capacity in Mobility." This study focused on integrating solar and wind energy sources to continuously charge electric vehicle batteries while in motion. Power generated from solar cells and wind turbines was fed into the battery through an inverter.

S.M. Ferdous et al. (2011) explored the concept of "Electric Vehicle Battery Charging During Motion" to address the limited energy storage capacity of electric vehicle batteries compared to conventional fuels. They proposed recharging batteries using renewable resources while the vehicle is in motion.

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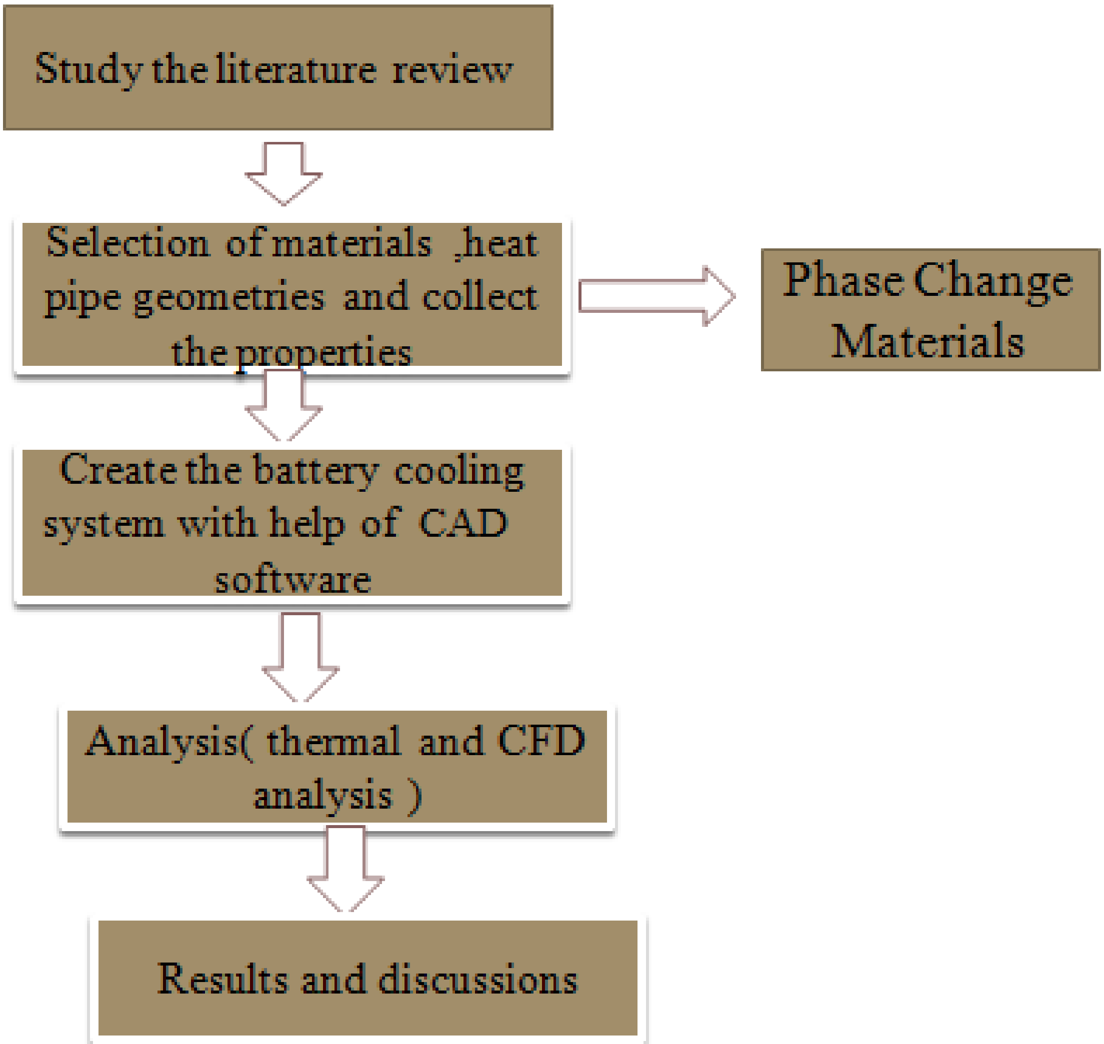
A. Pesaran et al. introduced "Thermal Performance Analysis of Electric Car Battery Modules and Packs" to facilitate precise thermal management system design for electric vehicles. Their study employed heat transfer principles and finite element analysis software to estimate thermal performance accurately.

Objectives:

- Increase heat transfer coefficient and mass flow rate across various heat pipe models.
- Enhance heat flux with different heat pipe geometries incorporating phase change materials.

Methodology



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3. Modeling and Analysis

In this section, various types of heat pipes essential for thermal and Computational Fluid Dynamics (CFD) analysis of a lithium-ion battery (LIB) cooling system for electric vehicles (EVs) are modeled. These heat pipes include different materials such as straight heat pipes and bend type heat pipes. The 3D models are developed utilizing CREO CAD software, followed by meshing for analysis purposes. Ansys software is employed to conduct both thermal analysis and CFD Computational Fluid Dynamics analysis.

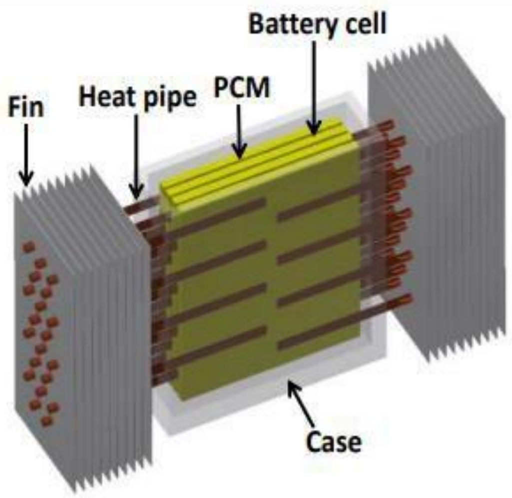

Figure 1: 3D model of Battery pack setup

Figure 1: 3D model of Battery pack setup

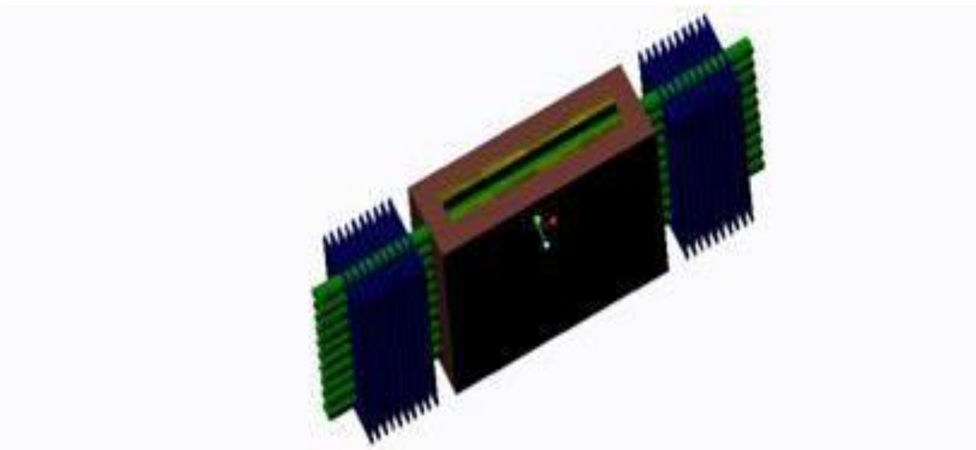

Figure 2: Straight Heat Pipes

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Bend Type Heat Pipes

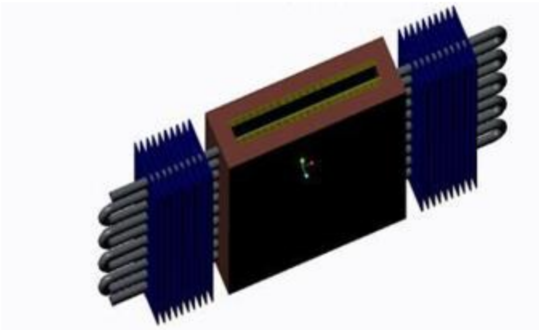

Figure 3: Bend type Heat Pipes

Introduction to FEA:

Finite Element Analysis (FEA) is a numerical method utilized for solving engineering and mathematical physics problems. It proves valuable for addressing issues with intricate geometries, loadings, and material properties where analytical solutions are unattainable. Such methods are preferred because analytical techniques often fail to address the complex real-world problems encountered in engineering. FEA is particularly useful for problems lacking precise solutions.

Introduction to CFD:

Computational Fluid Dynamics (CFD), a branch of fluid mechanics, employs numerical techniques and algorithms to analyze and solve problems involving fluid flows. Computers perform calculations necessary for simulating fluid and gas interactions with defined surfaces, set by boundary conditions. With high-speed computers, more accurate solutions can be obtained. CFD involves modeling and simulation based on numerical techniques for fluid flow and thermal analysis. Various numerical models can analyze heat and mass transfer, reactive flow, multi-phase flow, and combustion.

CFD Methodology:

1. Geometry and physical bounds are defined using CAD, followed by processing data to extract the fluid volume.
2. The fluid volume is divided into discrete cells (mesh), and physical modeling is defined, including equations for fluid motion, enthalpy, and radiation.
3. Boundary conditions are specified, detailing fluid behavior and properties at all bounding surfaces.
4. The simulation begins, and equations are solved iteratively for steady-state or transient conditions.
5. A postprocessor is employed to analyze and visualize the resulting solution.

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Material Properties:

For Cooling Fins:

- Density: 2719 kg/m^3
- Specific Heat: 871 J/kg-K
- Thermal Conductivity: 202.4 W/m-K

For Heat Pipes:

- Density: 2920 kg/m^3
- Specific Heat: 26.8 J/kg-K
- Thermal Conductivity: 11940 W/m-K

Phase Change Materials: RT50:

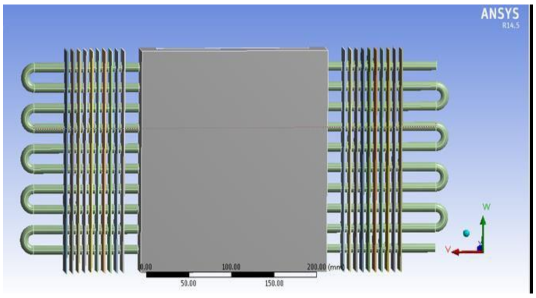
- Density: 753 kg/m^3
- Specific Heat: 2000 J/kg-K
- Thermal Conductivity: 0.2 W/m-K

RT35:

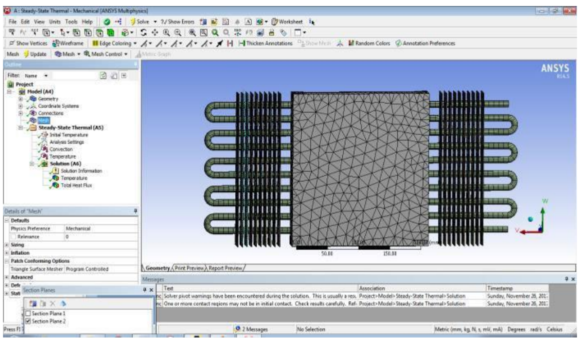
- Density: 768 kg/m^3
- Specific Heat: 1800 J/kg-K
- Thermal Conductivity: 0.35 W/m-K

CFD and Thermal Analysis of Lithium-Ion Battery Cooling System

Imported model



Meshed model



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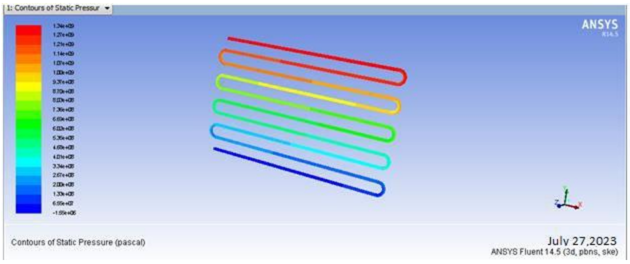
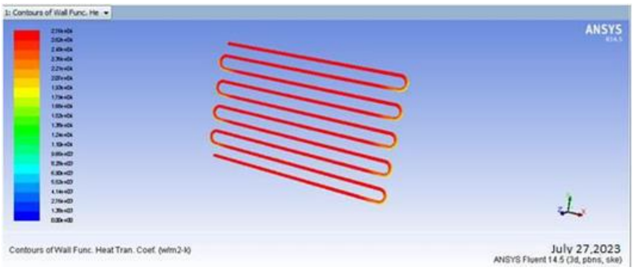
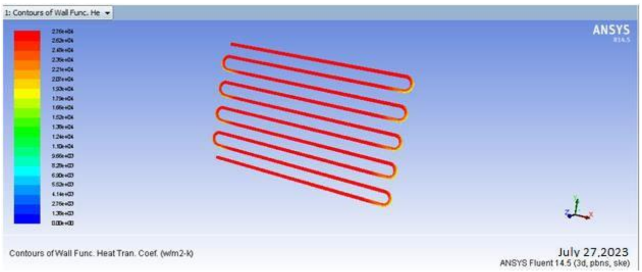
Pressure



Velocity



Heat Transfer Coefficient



Mass Flow Rate & Heat Transfer Rate

Mass Flow Rate	(kg/s)
inlet	0.19999996
interior-partbody	746.15308
outlet	-0.19846933
wall-partbody	0
Net	0.0015306324

Total Heat Transfer Rate	(w)
inlet	1177.5229
outlet	-1168.5139
wall-partbody	0
Net	9.0090332

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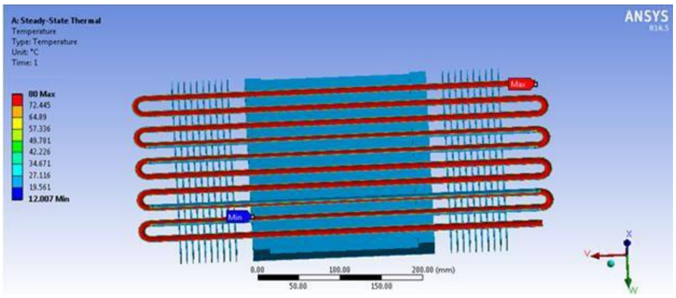
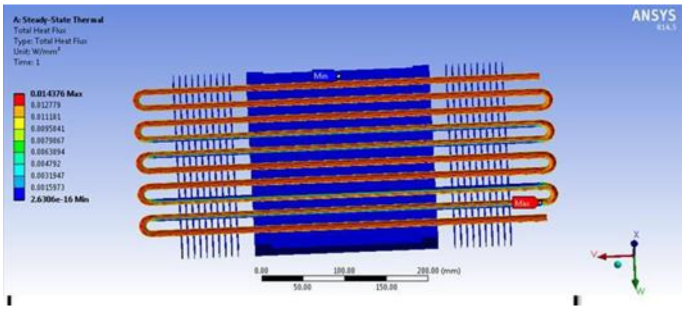
Velocity

Material- RT35 (Phase Change Material) Temperature



Heat flux



Analysis results and discussions

Fluid Analysis Results:

Case 1: Straight Type Heat Pipes

Mass Flow Rate (L/min)	Pressure (Pa)	Velocity (m/s)	Heat Transfer Coefficient (W/m^2-K)	Mass Flow Rate (kg/sec)	Heat Transfer Rate (W)
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+06	7.08e+03	0.001036	6.12
60	1.91e+07	4.29e+03	8.28e+03	0.00151	8.92
70	2.51e+07	5.02e+03	9.51e+03	0.00084	4.925

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Case 2: Bend Type Heat Pipes

Mass Flow Rate (L/min)	Pressure (Pa)	Velocity (m/s)	Heat Transfer Coefficient (W/m^2-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	0.00150	9.00329
60	7.87e+08	1.60e+04	2.29e+04	0.000625	3.2189
70	1.34e+09	2.00e+04	2.76e+04	0.0002172	2.3659

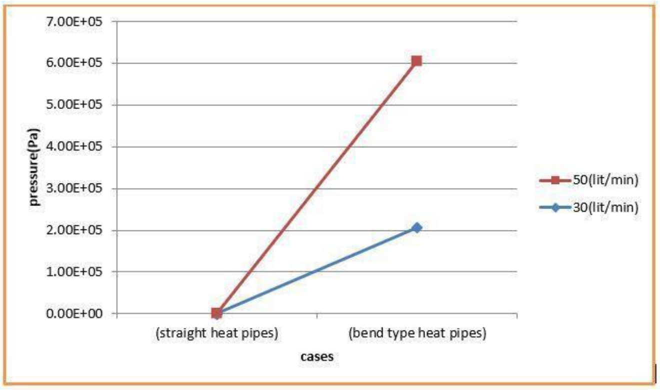
Thermal Analysis Results:

Models	Material	Temperature (°C)	Heat Flux (W/mm^2)
Design 1 (Straight Heat Pipes)	PCM RT50	19.213	0.020264
	PCM RT35	17.838	0.031486
Design 2 (Bend Type Heat Pipes)	PCM RT50	12.913	0.014391
	PCM RT35	12.007	0.014376

These results provide insights into the performance of different heat pipe configurations and materials in terms of fluid dynamics, thermal behavior, temperature distribution, and heat flux.

Graphs

Pressure



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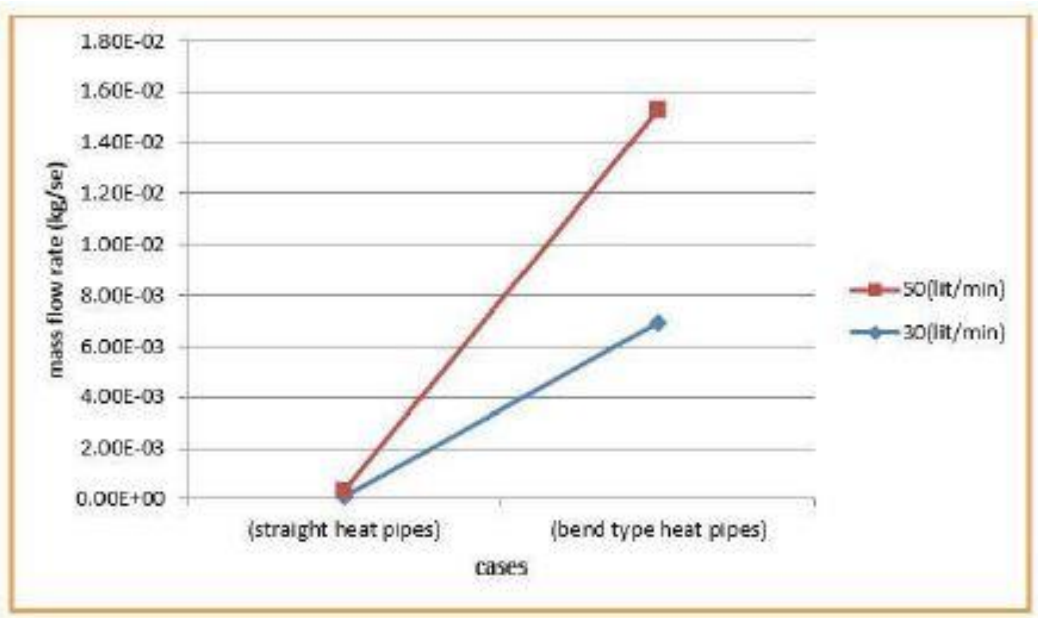
To find the maximum pressure with bend type heat pipes, we can refer to the provided data for Case 2: Bend Type Heat Pipes:

Mass Flow Rate (L/min)	Pressure (Pa)
30	3.97e+07
40	2.31e+08
50	2.48e+08
60	7.87e+08
70	1.34e+09

From this data, we can see that the highest pressure occurs at a mass flow rate of 70 L/min, with a pressure value of approximately 1.34e+09 Pa (1.34 billion Pascals). Therefore, the maximum pressure with bend type heat pipes is approximately 1.34e+09 Pa.

Mass flow rate



According to the plot, the maximum mass flow rate with bend type heat pipes.

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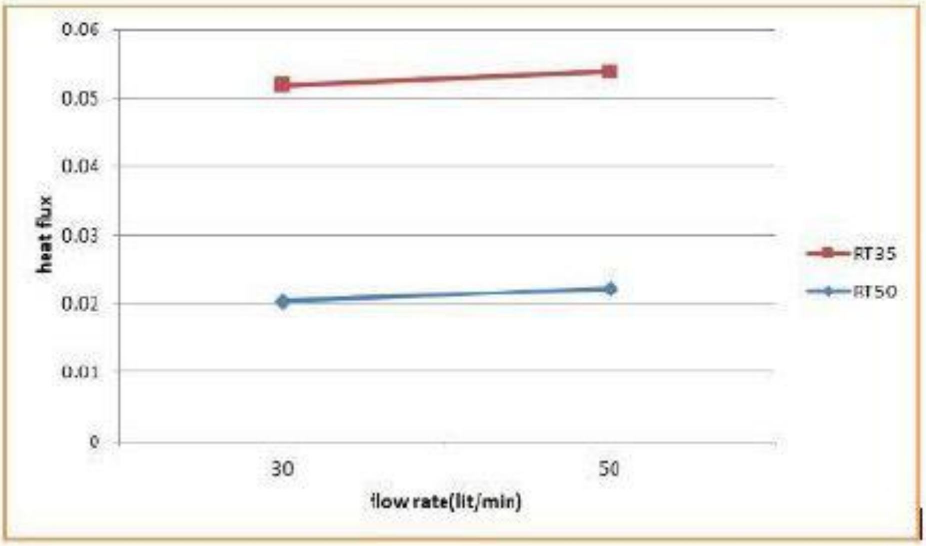
Heat Flux



According to the plot, the maximum Heat Flux is Possible with RT 35 over RT 50

CONCLUSION

In conclusion, lithium-ion batteries have emerged as primary power sources for electric vehicles and hybrid electric vehicles due to their superior performance compared to other alternatives. Ensuring the safety and improving the performance of battery packs requires maintaining them within acceptable temperature limits under ideal conditions.

Observing the results of the CFD analysis, it's evident that mass flow rate, heat transfer rate, and heat transfer coefficient values increase with increasing mass flow inlets. Particularly, the heat transfer rate is higher for Design 2 (bend type heat pipes).

Furthermore, thermal analysis reveals that the heat flux value is higher for the RT35 phase change material compared to RT50 phase change material, especially for Design 2 (U-bend type heat pipes). This suggests that Design 2 (U-bend type heat pipes) is a better model for the lithium-ion power battery cooling system.

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