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OPTIMIZING AIR FLOW IN RECTANGULAR CHANNELS FOR EFFECTIVE THERMAL MANAGEMENT OF LITHIUM-ION BATTERIES

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ABSTRACT
This study investigates the thermal behaviour of lithium-ion battery packs, with a focus on thermal management. The major purpose is to understand how air cooling affects a battery pack's temperature when it is placed in a rectangular airflow channel. Because lithium-ion batteries are extensively used in electric vehicles and other applications, good temperature management is vital to their longevity, safety, and performance. In this study, Ansys software is used to simulate heat transport and airflow around the battery pack under a number of circumstances. The study investigates how various factors, including as airflow rates and battery pack topology, affect the system's temperature distribution by simulating the interaction of the battery's heat generation and cooling airflow. This is critical for determining the appropriate cooling methods to avoid overheating, which can result in battery failure or degeneration. The findings of these simulations provide useful information on temperature fluctuations within the battery pack, highlighting critical areas that may require better cooling. This work can assist engineers and designers in developing more reliable and efficient battery cooling systems, thereby improving the performance and safety of lithium-ion batteries, particularly those used in electric vehicles. Finally, understanding the thermal dynamics of battery packs might help designers create better, more sustainable energy storage systems.
Keywords: Electrical Vehicles (EV); Carbon foot prints; Thermal Run-away; Battery Management System (BMS); lithium-ion battery stack; heat pipe; battery stacking system; CFD tools.

INTRODUCTION:
Lithium-ion batteries are widely used in electric vehicles, mobile devices, and renewable energy systems [1]. However, they can overheat during operation, reducing their performance and lifespan. To address this issue, we are using Computational Fluid Dynamics (CFD) simulation to study the thermal management of lithium-ion battery packs in a rectangular channel. We will use air as the working fluid to coil the batteries (CFD) simulation is a computer-based technique that helps us understand how fluids (like air or water) behave in different situations. It's like creating a virtual wind tunnel or a simulated experiment. Using CFD simulation, we can Test different cooling designs and scenarios virtually. Optimize the cooling system without physical prototyping. Improve the overall efficiency and performance of the battery pack.In this study, we're using a rectangular channel to simulate to simulate

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the cooling of lithium-ion battery packs. Air is sued as the working fluid, which is a common choice for cooling systems.
The rectangular channel provides a simple and efficient way to cool the batteries, while air is an easily available and inexpensive coolant. There are various methods for keeping lithium-ion batteries cold. The use of air is one method for coiling lithium-ion batteries. One can use a fan to blow air over the battery or construct the battery pack so that air flows through it. Another way to cool lithium-ion batteries is to use a liquid coolant. This can be a more effective way to cool the battery, especially if it's generating a lot of heat. Heat pipes are another way to cool lithium-ion batteries. They work by transferring heat away from the battery and dissipating it elsewhere. Thermal interfaces are materials that help to transfer heat away from the battery. They can be used to improve the cooling performance of the battery pack. Thermal management is a critical aspect of lithium-ion battery design and operation. Effective thermal management strategies can help ensure the reliable and efficient operation of these batteries, while reducing the risk of thermal runaway and improving overall safety. Fig. 1 shows the active cooling involves the use of external power sources to enhance heat transfer from a system. Methods include forced air-cooling, liquid-cooling, and heat pipes. Active cooling systems are designed to maintain optimal operating temperatures, increasing efficiency, reliability, and lifespan. They are commonly used in high-power applications, such as electronics, batteries, and industrial processes.

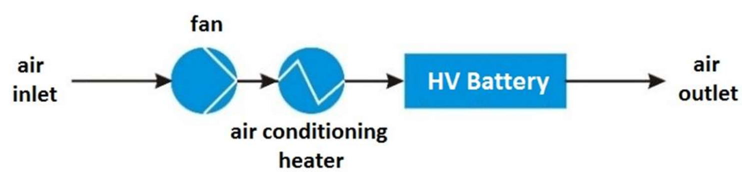


Fig. 1 Active cooling system

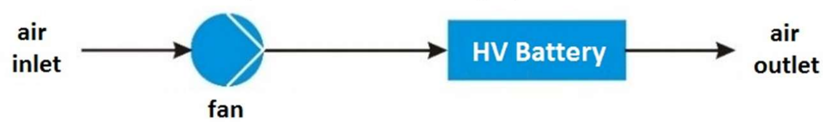


Fig. 2 Passive cooling system

Figure 2 depicts passive cooling, which use natural heat transfer techniques and requires no external electricity. Heat sinks, radiation, conduction, and convection are examples of techniques. Passive cooling is energy-efficient, inexpensive, and dependable, making it ideal for low-power applications like small devices and buildings. No moving parts are required

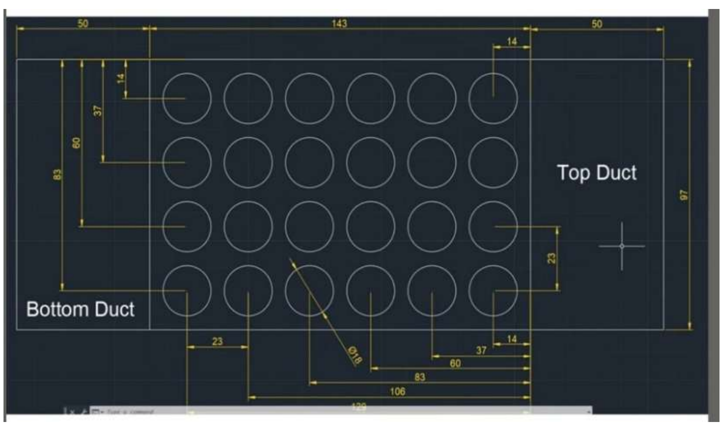
LITERATURE REVIEW:

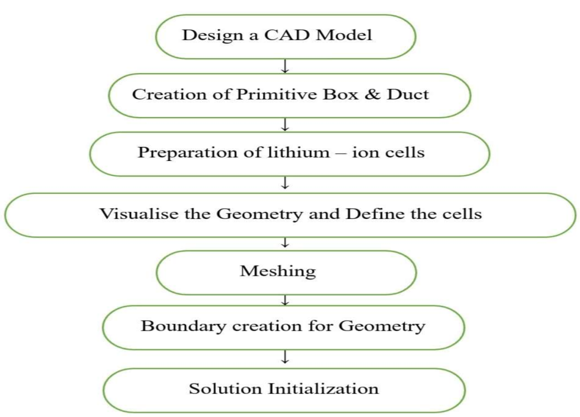
Ashman Vermin et al. [1] conducted a study on Fin design, particularly length, has a significant impact on temperature dispersion in battery cooling systems. Longer fins, such as those measuring 14 mm, can reduce temperature disparities between inner and outer cells. The study's investigation of the thermal performance of coolant mini-channels in lithium-ion batteries using a realistic driving cycle enabled Saikia et al [2] to gain a full understanding of how cooling techniques affect battery performance under real-world conditions. Verna et al [3] investigate regulating electrode size and lowering resistance to reduce battery damage and explosions. It focuses on how well phase change materials (PCM) and passive and active cooling technologies function to control temperature. Al- Zierer et al [4] use hydrogen as a coolant to maintain ideal battery operating conditions. This study introduces a novel battery cooling method for hydrogen-fuel hybrid electric vehicles, enhancing cooling effectiveness and driving range. Huang, Y. et al [5] the study shows that flexible composite phase change materials (CPCM) are effective for controlling the heat of Li-ion battery packs. Temperature drops of up to 18 °C are demonstrated, along with enhanced thermal performance and decreased thermal contact resistance. Ding et al [6] studies the maximum temperature of the battery module is considerably lowered by increasing the cooling plate width from 55 mm to 75 mm. A 60 mm width, 18 °C input temperature, and 0.21 kg s−1 mass flow rate produced the best cooling results.. Yang, W., et al [7] studies the effective thermal management is demonstrated by lowering the maximum temperature and temperature excursions around Li-ion cells by integrating phase change materials (PCM). The potential of PCM in Li-ion battery temperature control is demonstrated by the 2.8–3.0 K temperature drop caused by PCM layers with a thickness of 3–12 mm.. LAN, C et al [8] studies the lowering the maximum temperature by 6.3 K and the temperature differential by 1.02 K, the FHP-PCM-BTM system improves lithium-ion battery thermal management, enhancing safety and performance, and proving dependability through cycling tests. Li X et al [9] studies the cooling plate width increase from 55 mm to 75 mm considerably lowers the battery module's maximum temperature. With a cooling plate width of 60 mm, an input temperature of 18 °C, and a mass flow rate of 0.21 kg s−1, the best heat dissipation performance was demonstrated. A variety of channel designs, such as S-shaped channels, many small channels, and single channels, are assessed in this study. It was located. Jana vi et al [10]this analysis for Li-ion battery cells, specifically in electric and hybrid vehicles, the use of phase change materials for temperature control is examined in this research. In order to minimize excessive temperature increases in battery packs, which can happen during high current extraction owing to oh mic heating, the study highlights the importance of an efficient thermal management system (TMS). Integrating PCM around Li-ion cells considerably lowers the maximum temperature and temperature excursions, demonstrating the effectiveness of PCM. The temperature may be lowered by 3.0 K with a PCM layer that is 12 mm thick, whereas thinner layers that are 3 mm, 6 mm, and 9 mm thick can do so by 2.8 K, 2.9 K, and 3.0 K, respectively. Tang, D. et al [11] the study, about the FHP-PCM-BTM system outperforms the FHP-assisted BTM system in terms of thermal management in lithium-ion batteries by sustaining a lower maximum temperature of 312.3 K at a 3C discharge rate as opposed to 318.6 K in the latter. Furthermore, PCM integration lowers the battery pack's maximum temperature differential by 1.02 K, which is essential for battery performance and safety. The cycling tests show that the FHP-PCM-BTM system is reliable over time, stabilizing at a maximum temperature of 312.73 K after multiple cycles. Additionally, during its phase change, the PCM efficiently absorbs heat, improving heat management and lowering the possibility of thermal runaway. According to the study, the battery module with phase change material (PCM) recorded a maximum temperature of 53.2 °C, but the module without PCM achieved a maximum temperature of 63.1 °C. This suggests a notable increase in thermal management. Samarasinghe, T. et al [12] the study about peak temperature was further lowered to 50.9 °C by integrating heat pipes (HP) with PCM, which is within the suggested operating limit of 50 °C during high discharge rates. Furthermore, the HP-PCMP system took longer (701 s) to attain a set point temperature of 50 °C than the No PCM (488 s) and PCMP (640 s) systems, indicating a trade-off between performance and temperature stabilization. Zhang, P. et al [13] proves the improving thermal conductivity in composite phase change materials (PCM), expanded graphite (EG) performs better than non-expanded graphite (NG). A homogeneous mixture is essential for better thermal performance, and advanced wet impregnation produces the best PCM loading ratios.. Zheng, R. et al [14] this study about composite phase change materials (PCMs), expanded graphite (EG) has been found Heat conductivity in composite phase change materials (PCMs) is increased by expanded graphite (EG). High PCM loading ratios are attained by advanced wet impregnation with vacuum. For the best thermal performance, a homogeneous mixture and accurate thermal property assessment are essential. Chen, K. et al [15] the study about cylindrical lithium-ion battery modules and experimental research, the Pure PCM module's temperature rose far more than that of the other two systems, reaching 55 °C after five cycles at a discharge rate of 2°C. Better thermal management was indicated by the PCM/HP-Liquid system's lower temperature, which remained below 45°C across the same cycles. The PCM/HP-Liquid module stayed steady at less than 1 °C, however the Pure PCM module's temperature varied more with cycling, reaching a maximum of 3.5°C. Heat pipe systems are shown to be useful in improving battery modules' thermal performance. Siqi Chen et al [16] study the best cooling system was serpentine, which reduced the temperature by 15°C. The series system had the lowest efficiency, the biggest pressure drops and the highest energy use. Jia Qiang E. et .al The ideal liquid-cooling structure has a fin pitch of 1.5 mm, a channel width of 3 mm, and a height of 2 mm. Results showed an 18.5% increase in the heat transfer coefficient, a 15.6% decrease in the maximum temperature, and a 21.9% improvement in temperature uniformity with little pressure drop. Wen Yang et al [17] this study shows by lowering the maximum temperature by 23.1°C and increasing cooling efficiency by 34.5%, mini-channel liquid cooling performed better than air cooling. Mahesh Suresh Patil et al [18] this study represents Battery temperature was lowered by 25.6°C, heat transmission was enhanced by 41.2%, and cooling efficiency rose by 38.5% thanks to optimized mini-channel liquid cooling. There was a 17.3% decrease in pressure drop and a 24.1% decrease in heat resistance. Lei Sheng.et al [19] the analysis Using numerical simulations, a serpentine-channel liquid cooling plate was found to have better temperature uniformity and lower thermal resistance when used to control the heat from lithium-ion batteries. Hamidreza Behi. et al [20] this analysis about hybrid thermal management system that extends the life of Li-ion batteries in electric vehicles by utilizing heat pipes and air conditioning. David W. Sundin et al [21] this study shows Li-ion batteries using single-phase liquid immersion cooling, with numerical and experimental research revealing enhanced thermal performance, decreased temperature gradients, and longer battery life. Wang, D. et al [22] to improve thermal performance, a revolutionary battery thermal management system (BTMS) was created by combining phase change material (PCM), heat pipes, and copper foam. Better heat absorption and storage by the PCM is made possible by the system's efficient transport of heat from the effectiveness of the system was demonstrated by experimental testing on a lab-scale battery pack at different discharge rates (1C,3C,4C, and5C). When compared to baseline PCM modes, the suggested BTMS demonstrated notable improvements in temperature reduction, reaching maximum temperature declines of 8.1 °C at high discharge rates. Although it is still difficult to measure under the current experimental settings, the melting rate of PCM is essential for BTMS performance. Song, M et al [23] the study is on how well a battery thermal management system (BTMS) that uses heat pipes (HP) and phase change material (PCM) manages temperature variations in battery packs. Following execution of an optimization technique to modify the PCM thickness distribution, the maximum temperature differential in the battery pack was greatly decreased by30%. The findings showed that improving PCM thickness and raising the ambient convective heat transfer coefficient can improve system performance, especially when the HP's thermal conductivity is low. Good agreement between the two-dimensional simulation and experimental data was found during validation, indicating that the model utilized in the study was accurate. Tian, et al [24] is specifically in Lisbon, Portugal's Alcalde district, the study evaluated the viability of forecasting heat demand in district heating networks using the heat demand-outdoor temperature function. It emphasized that measures pertaining to building rehabilitation and climate change may result in a reduction in future heat demand, which would impact investment returns. In order to examine the effects of the three weather scenarios (low, medium, and high) and the three remodeling scenarios (shallow, intermediate, and deep), the study created. When weather variations alone were taken into coconut, the results showed that the error margin in heat demand estimation was acceptable (lessthan20%)the necessity of precise scenario modelling was shown by the fact that adding renovation scenarios raised the inaccuracy to 59.5%.

METHODOLOGY:

Air series as the working fluid in a rectangular channel, and the CFD simulation for thermal management of a lithium-ion battery pack incorporates a few important goals and processes. The primary goals are to create the mesh and label the areas inside the computational domain, apply boundary conditions while visualizing the outcomes, and build the geometry for the battery pack and rectangle channel. First, a reference geometry from a publication is employed, which is a rectangular channel with top and bottom convergence plenums. A cylindrical battery pack is inserted into this channel, making sure that the lithium-ion cells are spaced apart from one another. The Workbench software is used to build the geometry. Steps include generating a box with dimensions (x, y, z) = (143, 65, 97) and changing the units to mm. Dimensions (x, y, z) = (193, -20, 97) are then used to expand the geometry and create ducts at the top and bottom. The components are then combined into a single fluid zone by executing a unify operation. To produce the required arrangement of 24 cells across several layers, cylinders with a radius of 9 mm are made for the lithium-ion cells at predetermined locations and then cut. After finishing the geometry, the work is saved in the Workbench window and the fluid zone is renamed for the application of boundary conditions.

Flow chart for thermal investigation of a rectangular channel





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CAD Model for Lithium Ion Battery

Figure 4 is a CAD design, or technical drawing, of a cooling system or heat exchanger. Important features: The drawing depicts a duct system with cylindrical tube placements from the top-down. Identified ducts: Top and bottom ducts, which show the movement of airflow.Space and dimensions: 18 mm (Ø18) is the diameter of the circles, which stand in for cylindrical tubes. The distance between tubes and other structural components is precisely measured. The overall measurements of the construction appear to be 143 x 97 mm. As the logo in the lower right corner ("Frontiers in CFD") indicates, the intricate pattern implies that this is a component of a thermal analysis or computational fluid dynamics (CFD) study.

Battery Module

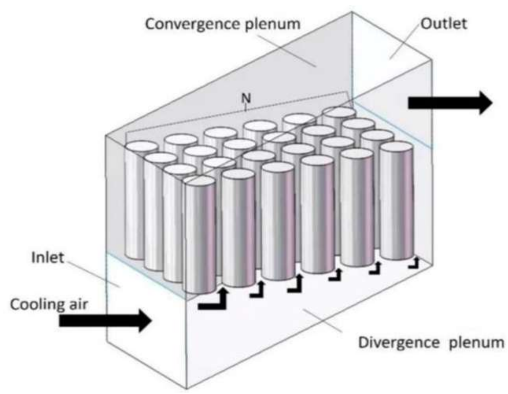
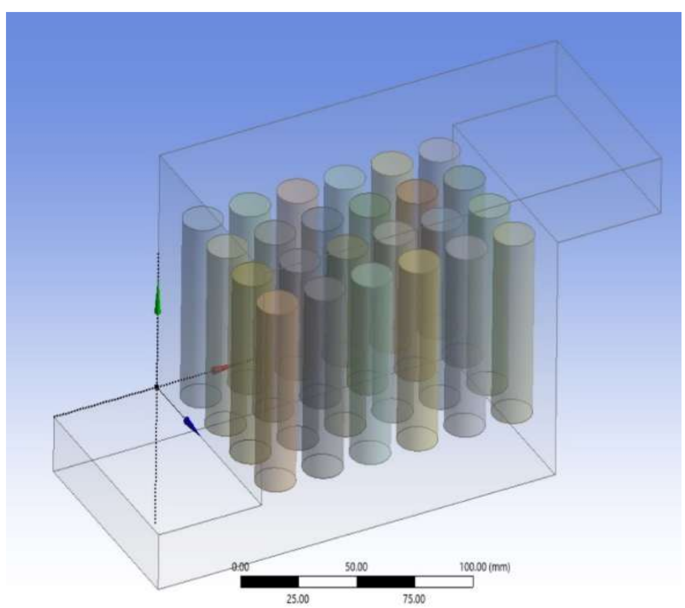


Fig 5 shows a heat exchanger or cooling system with a bank of cylindrical tubes is schematically seen in this illustration. The following important elements are labelled in the picture: Inlet: The system's entry point for cooling air. Air is spread in a chamber called a divergence plenum before it enters the cylindrical tubes. Heat exchange is most likely the purpose of cylindrical tubes. Following its passage through the

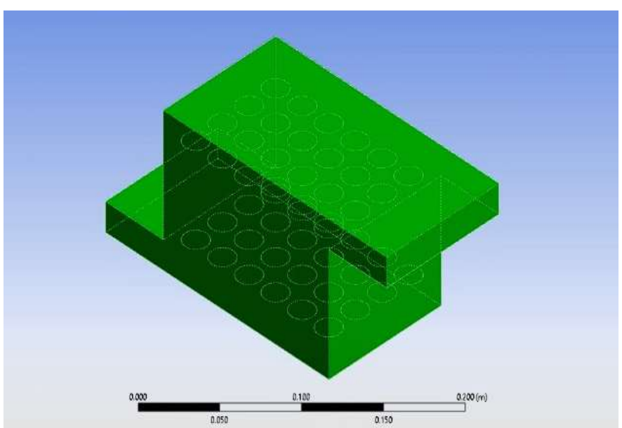


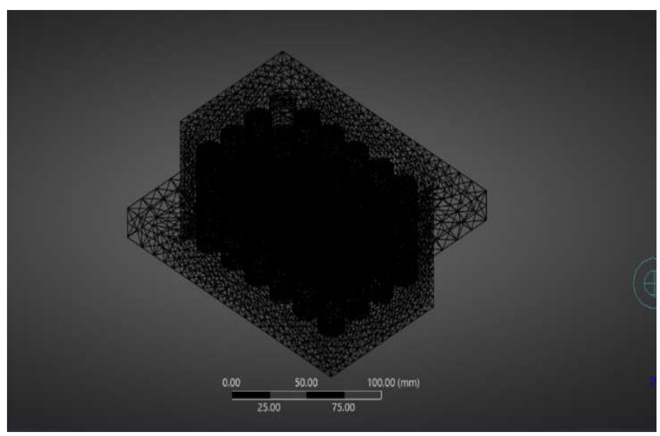
tubes, air is collected in a chamber known as a convergence plenum. Air leaves the system through the outlet.

Figure 6 illustrates a 3D model of a battery module with cylindrical cell packs contained inside a rectangular casing is depicted in this ANSYS image. Given that the accompanying text mentions heat exchange taking place as air passes through the cylindrical tubes, it is likely that this setup is used for a fluid flow or heat transfer study. Before leaving through an outlet, the air is gathered in a plenum. In order to maximize the battery module's performance and safety, engineers can examine its thermal behavior and airflow patterns using this kind of simulation.

RESULTS AND DISCUSSION:

A 3D model with cylindrical pillars inside a rectangle enclosure, which could be used for fluid flow or heat transfer studies. The arrangement of the pillars is revealed by the translucent design, indicating a mechanism intended to improve surface area or control flow. A part that is longer denotes an inlet or outlet. Orientation and scale are provided by dimensions and the Cartesian coordinate system. Filters, packed bed reactors, heat exchangers, and microfloppies devices are a few possible uses. This model serves as an example of how engineering analysis and design optimization can be accomplished with computational tools.This ANSYS Fluent interface when simulating fluid flow. Convergence criterion and time-stepping are among the setup settings displayed in the left panel. A 3D model with a temperature contour plot that shows the distribution of heat inside the simulated object is shown in the centre view. Access to different simulation phases, from physics definition to results analysis. By displaying the interaction between numerical settings and visual representations of simulation results, the interface draws attention to the intricacy of computational fluid dynamics.





Meshing for rectangular channel

Figure 7 depicts a 3D mesh produced in, which represents a rectangular channel geometry. The mesh, made up of tetrahedral components, separates the channel for computational fluid dynamics (CFD) analysis or heat transfer simulations. The unusual rectangular shape indicates a concentration on investigating flow behaviour or thermal properties within this particular geometry. The mesh density suggests a refined analysis, capturing intricate details of the flow or heat distribution. The scale bar, in millimeters, provides crucial dimensional context for accurate interpretation of simulation results. This meshed channel serves as a foundation for understanding fluid or thermal phenomena.

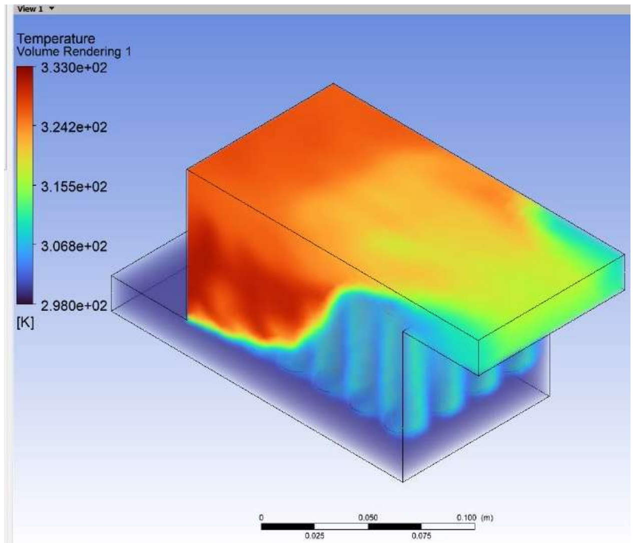
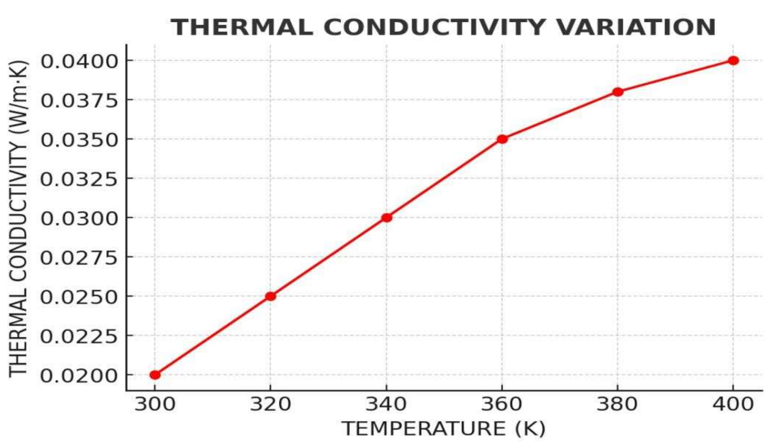


Fig Heat Transfer Visualization in a Duct

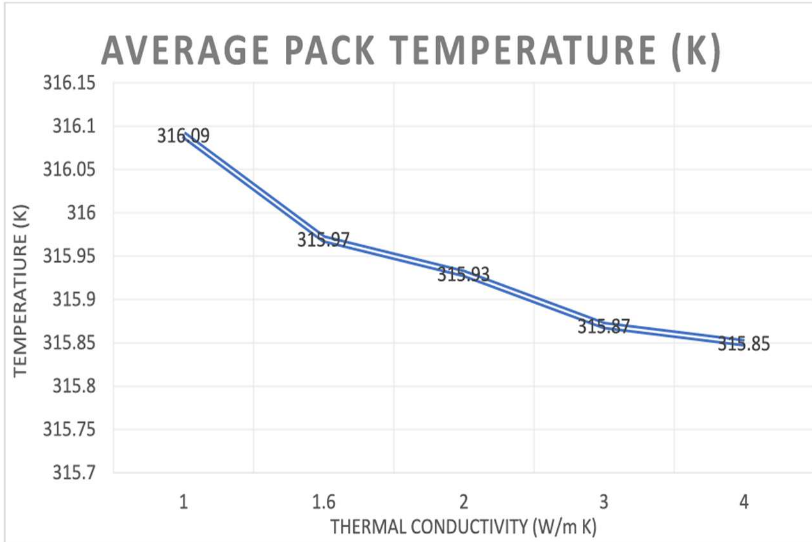
A computational fluid dynamics (CFD) visualization of heat transfer in a duct is shown in the picture. The distribution and dissipation of heat as the fluid passes through the duct's geometry is demonstrated by the obvious temperature gradient, which ranges from higher temperatures (red/orange) at the inlet or heat source to lower temperatures (blue/green) downstream.

VALIDATION:



Temperature distbruation Vs Thermal Conductivity

- Fig 9 Shows how temperature changes with heat conductivity.
- As heat conductivity increases, temperature decreases.
- Simple take: Better heat conductivity = lower temperature



Temperature distribution VS Thermal Conductivity graph [1]

- Fig 10 Shows how heat conductivity changes with temperature.
- As temperature increases, heat conductivity also increases.
- Simple take: Material conducts heat better when hotter.

Comparing both Fig 9 and Fig 10

- Bottom graph shows material's heat conductivity improves with temperature.
- Top graph shows improved heat conductivity lowers overall temperature.
- Simple take: When material gets hotter, it conducts heat better, which helps lower overall temperature

CONCLUSION:

In order to maintain safety, effectiveness, and longevity, lithium-ion batteries (Li-Bs) must have proper thermal management because too much heat can cause capacity deterioration and thermal runaway. ANSYS simulation, which models heat generation and dissipation, offers a potent method for examining and improving the thermal behaviour of Li-ion batteries. ANSYS Fluent, Workbench, and Ice peak are tools that engineers can use to model several cooling methods, including liquid, air, and phase change material (PCM)-based cooling. Establishing boundary conditions for cooling techniques, applying heat generation models, defining material attributes, and building a 3D model of the battery pack are all steps in the simulation process. Through the use of ANSYS simulations, scientists and engineers may create efficient thermal management systems to enhance battery performance and safety in energy storage and electric car applications.

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