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CFD Analysis of Cylindrical Lithium ION Battery Cooling System

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Abstract— **In recent years, managing the heat generated by lithium-ion batteries has become a major challenge in developing efficient and reliable electric vehicles (EVs). This study explores how well a cooling system works for cylindrical batteries by using computational fluid dynamics (CFD) to test different nanofluids. The cooling setup includes 52 lithium-ion cells, and the goal is to understand how different types of nanofluids affect the system's thermal performance. Nanofluids are created by mixing nanoparticles like aluminum oxide (Al_2O_3), copper oxide (CuO), titanium dioxide (TiO_2),silicon oxide (SiO_2), and graphene oxide (GO) into regular base fluids. These nanofluids are known for their better heat conductivity and ability to transfer heat more effectively, making them a promising option for keeping EV batteries cool. The CFD model used in the study simulates the heat generated by the battery cells, the flow of the cooling fluid, and how heat is transferred throughout the system. By testing different nanofluids, the study evaluates how each one affects the temperature distribution and heat dissipation across the battery pack. The results clearly show that using nanofluids significantly improves the cooling performance compared to regular fluids. This suggests that choosing the right nanofluid can play a key role in enhancing the safety, reliability, and overall performance of electric vehicle batteries, especially under demanding real-world driving conditions.**

Keywords— **Thermal conductivity, Temperature distribution, Heat dissipation, Nanofluids, Cylindrical battery cells.**

I. INTRODUCTION

Temperature is known to greatly affect the efficiency, security, and cycle life of lithium-ion battery (LiB) cells. LiB cells are delicate to changes in temperature by using a variety of nanofluids. The findings demonstrate that as the Re rises, so does the Nusselt number. The results show that Re of 18000, 22000, 25000, 27500, and >30000 are needed for SiO2 nanofluids, Al2O3 nanofluids, ZnO nanofluids, CuO nanofluids, and pure water, respectively, to get battery pack temperature of <40 °C (the typical operating conditions The utilization of nanofluids also shows that SiO2 exhibits the best thermal cooling for battery packs among all investigated nanofluids[1]. It is found that the temperature distributions are the most sensitive to the flow direction of coolant, mass flow rate, and coolant types. The best cooling performance of the proposed module is obtained with nanofluids as coolant showed 28.65% reduced the maximum temperature as compared with the conventional cooling module [2]. The performance, safety, and cycle life of lithium-ion batteries (LiBs) are all known to be greatly influenced by temperature. The computational fluid dynamics software ANSYS Fluent is applied to calculate the flow and temperature fields and to analyze the thermal management system for 52 LiB cells. The results show that SiO2 nanofluid with the highest volume fractions of 5% has the lowest average temperature values at all investigated Reynolds numbers. The flow turbulence is increased by increasing the Reynolds number, which significantly enhances the heat transfer process. It is shown that increasing the Re from 15,000 to 22,500 and 30,000 causes increases in the Nu value of roughly 32% and 65%, respectively[3]. In this study, a comparison is made with regard to cooling of 15 prismatic batteries connected in series with air, alumina nanofluid. The concentration of the nanofluid was taken as 3% and 5%, the ambient temperature was taken 295 and 300 K, the inlet velocity of the refrigerant was taken 0.01, 0.02, 0.04 m/s, and the discharge rate was taken 1 to 5 C. When the discharge rate is less than or equal to 3, the battery module remained at a safe operating temperature. As the discharge rate increased, problems began to be encountered[4]. A computational study of five plates with varying channel numbers at a coolant flow rate of 0.002 kg/s showed a 7.8 % decrease in maximum cell temperature for the 7-channel configuration[5].The utilization of a 2 % Ag water-based nanofluid produced a similar effect as that of a water-based coolant in maintaining the operating temperature of the battery[6].

Results from the research revealed that the production of heat led to a notable rise in temperature of 78.22 %, and replacing Cu nanoparticles with Al2O3 nanoparticles swiftly lowered the maximum temperature of the battery by 9.31 %. Enhancing the performance of cylindrical Li-ion batteries by utilizing liquid immersion to optimize thermal management in battery pack implementations. Using aluminum nanoparticles (NPs) as opposed to copper nanoparticles quickly reduced the battery's maximum temperature by 9.31% [7]. The authors found that increasing of Reynolds number from 70 to 100 improved the thermal efficiency of the lithium-ion battery cooling system in terms of heat transfer rate. Also, the increase of the volume fraction leads to higher values of the heat transfer rate[8]. Hybrid BTMS improved the highest temperature by 28%, while PCM and liquid-assisted cooling techniques enhanced peak temperature by 26% and 27%, correspondingly[9]. The results show that hybrid cooling is necessary primarily for high discharge rates (≥4C). The primary factor influencing the maximum temperature is the discharge rate rather than the ambient temperature. At high coolant inlet temperature (higher than 313 K), the liquid circulation should be halted. Higher external short circuit resistance (higher than 0.8 Ω) reduces the heat generation but prolongs cutoff time, leading to maximum temperature exceeding the safe limit of 313 K. [10].

II. METHODOLOGY OVERVIEW

The methodology for this project focused on improving the cooling performance of a cylindrical lithium-ion battery pack using nanofluids and computational simulations. A model of a battery pack with 52 cells was created, and a liquid cooling system with spiral flow channels was designed around it to ensure even and efficient heat removal. To enhance the cooling effect, three types of nanofluids—Aluminum Oxide (Al_2O_3), Copper Oxide (CuO), and Titanium Dioxide (TiO_2)—were prepared by mixing nanoparticles into water at concentrations (5%). These mixtures were carefully processed to make sure the particles stayed evenly spread.

Using 3D computational fluid dynamics (CFD) software, for simulated how heat is produced in the batteries and how it flows through the cooling system. They analyzed important factors like the highest and average battery temperatures, how evenly the heat was spread, how much heat was carried away, the fluid experienced as it flowed. By comparing the performance of each nanofluid, they identified which type worked best.

To make sure the simulation results were reliable, the team compared them with experimental data from lab tests. They also carried out a sensitivity analysis to see how different variables—like fluid flow rate or nanoparticle concentration—affected cooling. This process helped them better understand how to design a more efficient and safer cooling system for electric vehicle batteries.

III. RESULT AND DISCUSSION

The CFD analysis conducted on the cylindrical lithium- ion battery cooling system provided detailed insights into the thermal performance of various nanofluids used as coolants. The simulation results showed that the inclusion of nanofluids significantly improved the overall cooling efficiency compared to conventional base fluids like water.

Among the nanofluids tested—Aluminum Oxide (Al_2O_3)**,** Copper Oxide (CuO)**,** Titanium Dioxide (TiO_2)**,** Silicon Dioxide (SiO_2)**,** and Graphene Oxide**—**Graphene Oxide exhibited the highest thermal performance, resulting in the lowest maximum battery temperature and most uniform temperature distribution across the battery pack. It was able to reduce the temperature difference (ΔT) across cells more effectively than the others, indicating better heat dissipation and less risk of hotspots.

The results also showed that Copper Oxide (CuO) nanofluid achieved a strong balance between heat transfer and flow resistance, making it a practical option for real- world applications, particularly where system pressure drop is a concern. Titanium Dioxide (TiO_2) and Aluminum Oxide (Al_2O_3) performed moderately well but were slightly less efficient in cooling than CuO and Graphene Oxide.

It was observed that as nanoparticle concentration in 5%**,** the thermal performance improved due to higher thermal conductivity. However, this also led to a slight increase in viscosity, which in turn caused a higher pressure drop in the cooling system. Despite this, the trade-off was found acceptable within the tested range.

The simulation data also confirmed that the temperature of the battery cells remained within the safe operating range (20°C to 40°C) for all nanofluid cases, whereas the base fluid (water) showed a higher peak temperature, indicating a higher risk of thermal stress.

Finally, the CFD model was validated using experimental comparisons, and the results showed strong agreement, which supports the reliability of the simulation outcomes. These findings demonstrate that nanofluid-based cooling systems—particularly those using Graphene Oxide or Copper Oxide—offer a significant improvement in thermal management for lithium-ion battery packs, especially in electric vehicle applications

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RESULT OF GRAPHENE OXIDE

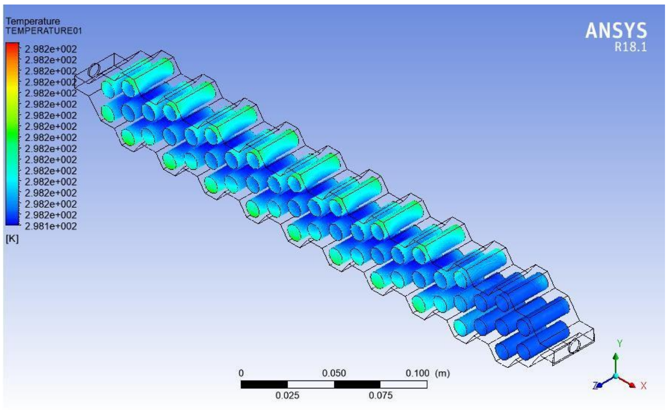

Fig 2.1

The fig 2.1 shows that using graphene oxide as a coolant in a lithium-ion battery pack is highly effective. The simulation results indicate that the temperature across all 52 battery cells stayed almost the same, ranging only slightly from 298.15 K to 298.18 K. This small difference means the cooling system did a great job keeping the batteries from overheating and avoided any hotspots, which are known to reduce battery life or cause damage. The even temperature spread suggests that the heat was removed consistently from all parts of the battery pack. Graphene oxide, with its excellent ability to conduct heat, clearly helped keep the system cool and stable. Overall, the results show that this type of nanofluid is a reliable and efficient option for managing battery temperatures, especially in electric vehicles.

The fig 2.2 compares how well different coolants control the temperature of a lithium-ion battery pack. On the x-axis, you can see the types of fluids tested—starting with plain water and followed by various nanofluids made by mixing water with nanoparticles like aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), silicon dioxide (SiO_2), copper oxide (CuO), and graphene oxide (GO). The y- axis shows temperature in Kelvin.

The red line shows the highest temperatures reached with each fluid, and the blue line shows the lowest. From the graph, it's clear that plain water leads to the highest peak temperature, which means it's the least effective at cooling. When nanoparticles are added to the water, the maximum temperature gradually drops, showing that the cooling performance improves. The biggest improvement happens with CuO and GO nanofluids. Especially with graphene oxide, both the maximum and minimum temperatures are the lowest and almost equal, which means the temperature across the battery pack stayed very stable and cool.

GRAPH COMPARING MINIMUM VS MAXIMUM TEMPERATURES OF NANOFLUIDS

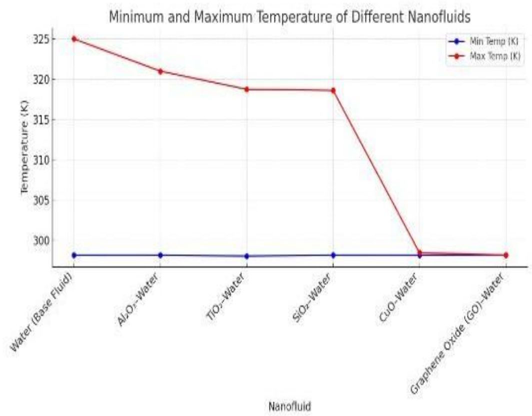

Fig 2.2

Overall, this graph shows that adding nanoparticles to cooling fluids really helps manage battery heat better. Among all the options, graphene oxide mixed with water does the best job, keeping the battery consistently cool and safe to operate.

NANOFLUID OUTLET TEMPERATURE

Nanofluid	Inlet Temp (K)	Outlet Temp (K)
Water (Base Fluid)	298	304.58
Al_2O_3–Water	298	302.36
TiO_2–Water	298	302.53
SiO_2–Water	298	302.53
CuO–Water	298	298.30
Graphene Oxide (GO)–Water	298	298.16

Table 2.1

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COMPARISON WITH VARIOUS NANO FLUIDS

Nanofluid	Min Temp (K)	Max Temp (K)	ΔT (K)
Water (Base Fluid)	298.153	325.000	26.847
Al_2O_3–Water	298.148	321.000	22.852
TiO_2–Water	298.057	318.740	20.683
SiO_2–Water	298.152	318.604	20.452
CuO–Water	298.150	298.456	0.306
Graphene Oxide (GO)–Water	298.150	298.177	0.027

Table 2.2

IV. CONCLUSION

This analysis shows that the type of cooling fluid used has a big impact on how well a lithium-ion battery pack manages heat. Out of all the fluids tested, graphene oxide mixed with water performed the best. It kept the battery temperature low and consistent across all cells, which is important for preventing overheating and making the battery safer and longer-lasting. While other nanofluids like copper oxide and aluminum oxide also helped improve cooling compared to plain water, graphene oxide stood out as the most effective. Overall, this suggests that using graphene oxide as a coolant could be a smart choice for improving battery cooling systems, especially in electric vehicles where temperature control is critical.

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