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Cfd Analysis On Battery Management System Using Nano-Fluids

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Abstract: Various sectors use battery packs and with the increase in use of electrical vehicles the need for a more efficient and smaller battery pack is significant. In the present study; we analyse the flow and heat transfer performance of a battery pack and use nano particles, mainly Graphene-Amine and Graphene-Oxide based nano particles mixed in solution of water and ethylene glycol. The nanofluid is prepared in laboratory and is tested in the experimental setup. The results are collected and then a CFD model is prepared and new designs and different fluids are to be tested. The impact of the stud100y focuses on maintaining or optimizing battery operating temperatures to improve the performance and increase efficiency of the system.

***Index Terms* - Battery Pack, Nano particles, CFD fluid flow and heat transfer, Graphene Amine, Graphene Oxide.**

I. INTRODUCTION

There is an increasing demand for high-performance battery management systems (BMS) in electric vehicles (EVs) and renewable energy (RE) storage has determine the need for efficient thermal management of Battery used in Electric Vehicles (EVs). During operation, batteries produce significant amounts of heat that, if left uncontrolled, may lead to thermal runaway, reduced performance, and potential safety hazards. To combat these challenges, scientists are turning to innovative cooling solutions enhanced with nanoparticles. By integrating these nanomaterials into traditional cooling fluids, they significantly boost thermal conductivity, enabling faster heat removal and more stable temperature control in battery systems.

Computational Fluid Dynamics (CFD) analysis plays a pivotal role in evaluating and optimizing the cooling performance of BMS by simulating heat transfer and fluid flow characteristics. Introducing nanoscale particles into traditional heat transfer fluids produces measurable improvements in two key thermal properties: the medium's ability to conduct heat and its overall cooling effectiveness. Through computational fluid dynamics (CFD) modelling, engineers can systematically evaluate critical thermal performance metrics - including spatial temperature variations, pressure differentials, and fluid dynamics patterns - to optimize cooling system designs for battery applications.

This study reveals that using CFD for determining how nano-fluid particles influences the cooling of battery in BMS. By modelling different nanoparticle concentrations, flow rates, and cooling channel geometries, the analysis aims to identify optimal cooling strategies that enhance battery performance, longevity, and safety while minimizing energy consumption. The insights gained from this CFD analysis can contribute to the development of next-generation thermal management systems for high-power battery applications.

II. GRAPHENE NANOPLATELETS

(Jindal et al.,2022)This study concludes that the inclusion of GNPs increases the rate of heat transfer compared to the pure EG/water coolant used in active BTMS. Only EG/water without GNP decreases the peak temperature by 10 °C which increases to 33.15 °C when GNPs are added. The study presents the optimum concentration of GNPs in given conditions to be 0.003 vol% after which increasing the concentration of GNPs have shown decrement of temperature to be negligible with almost constant heat flux of 2.145e06 W/mK. With the addition of only 0.001 vol% GNP the peak temperature reduces by 52% which increases to 55.25% at 0.003 vol% and remains same after that. Through this study it is recommended to omit the increment of GNPs concentration beyond optimum level, as negative effects may start to overcome decreasing overall heat transfer rate. Although the study is limited to computational analysis it offers to set a vantage point for the potential future experiments using GNPs.

III. GRAPHENE AMINE-BASED NANO COOLANT

(Joshi et al., 2024). In the current investigation, nanoparticles of graphene amine are employed to synthesise nano coolant. At coolant temperatures at the inlet vary from 50 ◦C to 80 ◦C, an EG/DW mixture based on nanoparticles is used at a weight concentration of 0.1 %. The nanofluid's flow rate ranges from 3 l/min to 9 l/min. After conducting an extensive experimental and computational analysis on the efficiency of an automotive radiator using nanofluids, focusing on aspects such as the convective heat transfer rate, heat transfer coefficient, and Nusselt number, the subsequent conclusions were drawn.

• Inlet coolant temperature of 80 ◦C and flowrate of 9 l/min were found to be the optimal conditions to improve heat transfer characteristics using nano coolants. At 9 l/min and 80 ◦C, a notable enhancement in the heat transfer rate, with an increase of 54.3 %, was observed. The experimental and numerical investigations of the heat transfer characteristics of nano coolant were in agreement with an average deviation of 20 %. The present study has limitations on the CFD model adopted while capturing the nano-level behaviour of the coolants used.

• Maximum convective heat transfer enhancement is 138 % for GA compared to de-ionised water.

• Compared to other nano coolants, GA demonstrated superior thermal performance.

• Improving the thermophysical properties of Nanofluids have the potential to guarantee a more compact radiator design by minimizing its size and weight. This reduction not only results in reduced fuel demand for same performance but also enhances design flexibility and promotes the creation of eco-friendly vehicles.

• Efficient nano-coolants are essential for battery thermal management systems to cater to increasing power demands and reduce operational hazards caused by overheating.

The work presented is limited to study of heat characteristics of radiator using nano coolant infused with graphene amine nanoparticle at fixed 0.1 wt %. Results of heat transfer characteristics with 0.05 %, 0.15 % and 0.2 % wt. % of nano coolants are not presented in this work. The future scope of the work can involve nano coolants prepared with higher dosage of the nanoparticles. The study can also involve hybrid nano coolants using binary and tertiary nanoparticles in the base fluids.

IV. MgO/CuO/Al2O3 WATER-BASED NANOFLUIDS

(Karimi et al.,2020). In this paper the numerical CFD technique is employed to investigate the heat transfer performance of the MgO/CuO/Al2O3 water based nanofluids in a circular tube exposed to a constant heat flux of 500 W m−2 at a wide range of Reynolds numbers in the presence of nanoparticles aggregation. Since the aggregation of the solid nanoparticles occurs in the real cases, it seems to be an influential factor which must be taken into consideration in the nanofluid heat transfer CFD simulation. A satisfactory agreement between the experimental and predicted results underlined the importance of aggregation effect in the simulations. The predicted results support the idea that the heat transfer coefficient elevates due to increase in the Reynolds number and the nanoparticle volume concentration. It is demonstrated that the increasing nanoparticle concentration enhances the heat transfer in low values, while the aggregation of nanoparticles at high concentrations leads to diminish the heat transfer capability of the nanofluid due to decreasing heat transfer coefficient. The CFD model with aggregation is capable of predicting the heat transfer coefficient about two times better and more accurate than the CFD model without aggregation. These findings represent that the implementation of the PBM with an accurate initial nanoparticle size distribution is a good CFD strategy to simulate the heat transfer of nanofluids and is suggested for further studies.

V. Heat Transfer Characteristics of Battery Thermal Management System Using Carbon derived Nano-Coolants

(Samarth et al.,2025)In this paper nanofluids with a weight concentration of 0.1% in a blend of ethylene glycol (EG) and distilled water was utilized and revealed that graphene amine-based nanofluids significantly outperform graphene oxide and metallic nanofluids. Specifically, graphene amine-based nanofluids exhibited a 91% increase in heat transfer rate, 115% increase in convective heat transfer coefficient, 96.8% increase in Nusselt number, and a 26.8% decrease in Reynolds number compared to conventional coolants. A maximum temperature rise of 138% was observed for graphene amine-based nanofluids with an EG/W base fluid ratio of 60:40, demonstrating superior cooling efficiency. Key performance metrics evaluated include temperature reduction, heat transfer rate, convective heat transfer coefficient, Nusselt number, and Reynolds number.

VI. CONCLUSIONS

The CFD analysis of nanofluid-based cooling for battery management systems demonstrates significant improvements in thermal performance compared to conventional cooling methods. By incorporating nanoparticles into the coolant, the thermal conductivity and heat dissipation capabilities are enhanced, leading to more efficient temperature regulation. The simulations reveal optimized temperature distribution, reduced hot spots, and better flow characteristics within the battery pack, contributing to improved safety and longevity.

Key findings from this study include:

- Enhanced heat transfer efficiency
- due to nanoparticle dispersion.
- Lower peak temperatures, minimizing thermal runaway risks.
- Improved cooling uniformity across battery cells.
- Potential for energy-efficient thermal management solutions.

Results demonstrate nanofluids' capacity to redefine battery thermal management paradigms. Further development must address three critical aspects: material stability under cyclic loading, production cost analysis, and manufacturing scalability. The study establishes foundational understanding for thermal management innovations in electrified transportation and renewable energy infrastructure.

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