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Investigating the experimental effect of TiO_2/SiC hybrid nanoparticles on the heat transfer performance of car radiator coolant

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Extended Abstract

Introduction

Improving thermal efficiency and reducing energy consumption in heat exchangers have long been key objectives in thermal engineering research. Among conventional enhancement techniques, modifying the base fluid has proven to be a more effective and economical approach than increasing the size of heat exchangers. In this context, nanofluids—formed by dispersing metallic or non-metallic nanoparticles into a base fluid—have demonstrated significant potential for enhancing heat transfer performance by improving the thermophysical properties of the coolant. The heat transfer behavior of nanofluids is strongly influenced by several parameters, including nanoparticle type and concentration, particle size, operating temperature, flow velocity, and base fluid characteristics. In automotive engineering, optimization of engine cooling systems is of particular importance, as enhanced heat dissipation can improve engine performance, reduce radiator size, and lower manufacturing costs. Numerous experimental and numerical studies have confirmed that the use of nanofluids in automotive radiators leads to higher convective heat transfer coefficients, increased Nusselt numbers, and overall improvements in cooling efficiency compared to conventional coolants. More recently, hybrid nanofluids, which consist of suspensions of two or more different nanoparticles within a single base fluid, have emerged as an advanced class of heat transfer fluids. Previous investigations have shown that hybrid nanofluids can outperform single-component nanofluids by providing superior thermal performance, enhanced convective heat transfer, and greater temperature reduction in automotive cooling applications. However, from an industrial perspective, hybrid nanofluids are still largely in the research and development stage.

Accordingly, the present study focuses on the experimental investigation of a hybrid nanofluid composed of titanium dioxide (TiO_2) and silicon carbide (SiC) nanoparticles dispersed in ethylene glycol. The novelty of this work lies in employing different mixing ratios of these nanoparticles and systematically evaluating their effects on the thermophysical properties of the coolant and the cooling performance of an automotive radiator used in a Pride vehicle. The findings aim to provide further insight into the potential of TiO_2/SiC hybrid nanofluids for enhancing automotive engine cooling systems.

Materials and Methods

In this study, the thermal behavior and heat transfer performance of nanofluids and hybrid nanofluids were investigated in an experimental setup simulating an automotive engine cooling system. The governing relationships for key thermophysical properties, including volume fraction, density, viscosity, thermal conductivity, and specific heat capacity, were employed to evaluate their influence on the convective heat transfer coefficient and Nusselt number. Well-established theoretical models were adopted to predict the thermophysical properties of both single-component and hybrid nanofluids. A laboratory-scale cooling system was designed to replicate the operating conditions of an automotive radiator and consisted of an aluminum radiator, a centrifugal pump, a controlled heating unit, and temperature measurement instruments. The coolant was heated in a thermal reservoir and circulated through the radiator, where inlet and outlet temperatures were recorded. Based on the experimental data, the heat transfer rate, convective heat transfer coefficient, and Nusselt number were calculated.

To examine the effect of nanoparticle concentration and composition, a design of experiments approach was applied to a hybrid nanofluid based on ethylene glycol containing titanium dioxide (TiO_2) and silicon carbide (SiC) nanoparticles. Several nanofluid formulations with a constant total nanoparticle mass fraction were tested under different operating temperatures. The preparation process involved magnetic stirring, probe ultrasonication, and ultrasonic bath treatment to ensure uniform dispersion and long-term stability of the nanoparticles. Stability

assessments confirmed negligible sedimentation over extended periods. Furthermore, the thermophysical properties of the prepared nanofluids, including viscosity, thermal conductivity, boiling point, and freezing point, were experimentally measured. The results demonstrated that the addition of nanoparticles, particularly in hybrid configurations, significantly enhances the thermal properties of the base fluid. These improvements indicate the strong potential of TiO_2 /SiC hybrid nanofluids to enhance the cooling performance and thermal efficiency of automotive engine cooling systems.

Results and Discussion

The experimental results demonstrated that the addition of TiO_2 /SiC hybrid nanoparticles to ethylene glycol significantly enhances the thermophysical properties of the coolant. Thermal conductivity increased with the incorporation of hybrid nanoparticles, and the highest enhancement was observed for the nanofluid containing 3% TiO_2 and 2% SiC, showing an approximately 15% increase compared to the base fluid. This improvement is mainly attributed to the intensified random motion of nanoparticles and their microscopic interactions within the fluid. The presence of nanoparticles led to a noticeable reduction in the freezing point of the coolant. At a total nanoparticle concentration of 5%, the freezing point decreased by nearly 11%, which is particularly advantageous for automotive applications operating under low-temperature conditions. Conversely, the boiling point of the coolant increased from that of the base fluid to approximately 120 °C with nanoparticle addition. Since the total nanoparticle concentration was kept constant, the type of nanoparticle had no significant influence on the boiling point variation. Viscosity measurements revealed that nanoparticle addition resulted in an increase in coolant viscosity. Incorporating 5% nanoparticles caused an approximately 14.8% rise in viscosity, while variations in nanoparticle composition did not lead to significant changes. This indicates that nanofluid viscosity is predominantly governed by the total nanoparticle concentration rather than the specific hybrid composition. Thermal performance evaluation of the radiator showed that increasing the flow rate and fluid velocity led to higher Nusselt numbers and improved convective heat transfer. Among the tested formulations, the hybrid nanofluid containing 2% SiC and 3% TiO_2 exhibited the best thermal performance. Across all investigated temperatures and flow rates, this nanofluid achieved an average Nusselt number enhancement of approximately 20% compared to the base fluid. These findings highlight the synergistic effect of hybrid nanoparticles and confirm the strong potential of TiO_2 /SiC hybrid nanofluids for improving heat transfer efficiency in automotive engine cooling systems. Using the Moffat uncertainty analysis method, the uncertainty of the calculated Nusselt number was evaluated, and the resulting relative error in the Nusselt number was determined to be 1.7%.

Conclusion

The addition of nanoparticles to the base fluid significantly increased density and enhanced heat transfer performance, with TiO_2-based nanofluids exhibiting higher density than SiC-based formulations. Hybrid TiO_2/SiC nanofluids demonstrated superior thermal behavior, achieving a maximum thermal conductivity enhancement of approximately 15% for the 3% TiO_2–2% SiC composition. Incorporating 5% nanoparticles reduced the freezing point by about 11% and increased the boiling point relative to the base fluid, while the nanoparticle type showed no significant effect on these properties. Although viscosity increased with nanoparticle addition, variations in nanoparticle type had a negligible impact when the total concentration was kept constant. Overall, the NF-2%SiC-3%TiO_2 formulation delivered the best convective performance, resulting in an approximately 20% increase in the Nusselt number across all operating conditions.

Key words: Nanofluid, hybrid, ethylene glycol, cooling, radiator

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