Experimental Investigation of Nano-Coolants on Heat Dissipation in Engine Cooling Systems

Sharun Mendonca[1*], Ravikantha Prabhu[1], Pavana Kumara Bellairu[1], Rudolf Charles DSouza[1]

[1]Department of Mechanical Engineering, St Joseph Engineering College, Mangaluru, India.

Abstract

The efficiency and durability of internal combustion engines significantly depend on effective thermal management. Conventional engine coolants often struggle to provide optimal heat transfer under increasing engine loads and operating temperatures. This study investigates the performance of nano-coolants—base fluids enhanced with dispersed nanoparticles—in improving the heat dissipation characteristics of engine cooling systems. Aqueous suspensions of aluminum oxide (Al_2O_3), copper oxide (CuO), and silicon dioxide (SiO_2) nanoparticles were prepared at varying concentrations and tested in a standard liquid-cooled engine system. Experimental trials were conducted under controlled conditions to measure parameters such as coolant temperature drop, heat transfer coefficient, thermal conductivity, and engine surface temperature profile. The results showed that nano-coolants, particularly those with Al_2O_3 at 0.1 wt%, demonstrated a noticeable increase in heat transfer efficiency compared to conventional ethylene glycol-based coolants. The study also discusses the stability, flow behavior, and material compatibility of the nano-coolants. The findings suggest that nano-coolants hold substantial promise in enhancing engine thermal management and may contribute to improved fuel efficiency and engine lifespan.

Keywords: Nano-coolants, Heat dissipation, Engine cooling system, Thermal conductivity, Aluminum oxide nanoparticles

1.Introduction

Internal combustion engines (ICEs), widely used in transportation and industrial applications, generate a significant amount of heat during operation due to fuel combustion and frictional losses. If not dissipated effectively, this excess heat can lead to engine overheating, component degradation, reduced efficiency, and even failure. Hence, a robust cooling system is essential to maintain optimal engine performance and longevity. Traditional engine coolants, primarily water or ethylene glycol mixtures, are designed to absorb and carry away heat from critical engine parts. However, these conventional fluids possess limited thermal conductivity, which restricts their heat transfer capabilities, especially under high load or extreme temperature conditions (Arivazhagan, 2023).

Recent advancements in nanotechnology have introduced a new class of heat transfer fluids known as nano-coolants, which are engineered by dispersing nanoparticles such as aluminum oxide (Al_2O_3), copper oxide (CuO), and silicon dioxide (SiO_2) into base fluids. These nanoparticles, typically less than 100 nm in diameter, possess significantly higher thermal conductivities compared to traditional fluid molecules. Their inclusion enhances the effective thermal conductivity of the base fluid, promoting improved convective heat transfer. Furthermore, the increased surface area and Brownian motion of the nanoparticles contribute to better energy transport within the fluid medium (Jadeja, 2023).

The potential of nano-coolants to revolutionize engine cooling has attracted considerable research interest over the last two decades. However, their practical application still faces challenges related to nanoparticle stability, sedimentation, corrosion, and compatibility with engine materials. Therefore, experimental studies are vital to assess the feasibility of nano-coolants in real-world engine systems, ensuring their safety, reliability, and performance under varying operational conditions (Bargal, 2025).

This study aims to experimentally investigate the thermal performance of different nano-coolants in a liquid-cooled engine setup. Specific objectives include evaluating the effect of nanoparticle type and concentration on coolant thermal properties, analyzing the temperature distribution and heat transfer rates, and comparing the results with standard coolants. The research also addresses practical concerns such as dispersion stability, flow behavior, and material interaction. By understanding the heat dissipation enhancement offered by nano-coolants, this work contributes toward developing advanced cooling solutions for more efficient, compact, and thermally stable engine systems (Lunga, 2023).

2.Literature Review

Over the past two decades, significant research has been directed toward improving engine cooling technologies, with a strong focus on enhancing the thermal conductivity of coolant fluids (Saxena, 2018). Conventional coolants such as water, ethylene glycol (EG), or their mixtures are widely used in automotive applications; however, their limited heat transfer capabilities restrict the cooling system’s effectiveness under high thermal loads. To overcome this limitation, the concept of Nano fluids, has gained traction. These fluids involve the suspension of nanoscale particles in base fluids, leading to improved thermophysical properties such as thermal conductivity, specific heat, and convective heat transfer coefficient (Reddy, 2019).

Numerous studies have demonstrated the potential of nanofluids in enhancing cooling performance. For instance, it is observed that the thermal conductivity of water-based Al_2O_3 nanofluids increased significantly with temperature and nanoparticle volume fraction. It is reported a 40% increase in thermal conductivity of ethylene glycol-based nanofluids containing copper nanoparticles. These findings confirm that the addition of metal or metal oxide nanoparticles can significantly enhance the thermal performance of traditional coolants (Al-Araji, 2021).

In the context of engine cooling systems, performed an experimental study using Fe_3O_4/water nanofluid in a radiator and observed a 17% increase in heat transfer compared to the base fluid. It is examined CuO-based nanofluids in automotive cooling applications and found enhanced convective heat transfer with minimal penalty in pumping power. However, these improvements depend heavily on factors such as particle size, concentration, base fluid compatibility, and flow regime (Gakare, 2019).

Despite the promising results, several challenges have been reported. Nanoparticle agglomeration and sedimentation remain primary concerns, affecting long-term stability and performance. Furthermore, researchers such as have raised issues regarding the erosion and corrosion potential of nanofluids when circulated through engine parts. Efforts to address these challenges include the use of surfactants, surface coatings, and optimized particle shapes (Shankara, 2020).

The literature suggests that while nano-coolants offer a significant opportunity for heat transfer enhancement, further experimental investigation under real engine conditions is essential. Most studies have focused on theoretical modeling or laboratory-scale heat exchangers, creating a gap in application-specific research. This study aims to address this gap by evaluating nano-coolants in a working engine environment, comparing performance metrics such as temperature reduction, heat transfer coefficient, and coolant stability (Sandhya, 2020).

3.Methodology

The experimental investigation was conducted using a single-cylinder, four-stroke, water-cooled diesel engine coupled with a loading unit. The engine was operated at a constant speed with varying loads to simulate real-world operating conditions. Three nano-coolants were prepared by dispersing nanoparticles—Aluminum Oxide (Al_2O_3), Copper Oxide (CuO), and

Silicon Dioxide (SiO_2)—into a base fluid of distilled water and ethylene glycol (50:50 by volume). Nanoparticles were used at concentrations of 0.05 wt% and 0.1 wt%. Sodium dodecyl sulfate (SDS) was used as a surfactant to improve dispersion stability. The mixtures were sonicated using an ultrasonic processor for 60 minutes to achieve uniform distribution and prevent agglomeration (Sahu, 2024).

The prepared nano-coolants were circulated through the engine's cooling jacket using a closed-loop cooling system equipped with a pump, radiator, and temperature sensors. Thermocouples were placed at the coolant inlet and outlet, engine block, and radiator to measure temperature variations. A flow meter and data acquisition system were used to monitor coolant flow rate and record real-time thermal data. The convective heat transfer coefficient was calculated using standard energy balance equations (Dushyanthkumar, 2024).

Each test was repeated three times for accuracy, and the results were compared with those from a conventional coolant to evaluate performance improvements in heat dissipation.

Experimental Setup:

Engine Type: Single-cylinder, 4-stroke, water-cooled diesel engine

Coolant Flow Rate: 3 L/min (constant)

Base Coolant: 50:50 Distilled Water + Ethylene Glycol

Nanoparticles Used: Al_2O_3, CuO, SiO_2

Concentrations Tested: 0.05 wt% and 0.1 wt%

Surfactant: SDS (0.05 wt%)

Engine Load Conditions: 25%, 50%, 75%, 100%

Coolant Type	**25% Load**	**50% Load**	**75% Load**	**100% Load**
Base Coolant Only	6.1	9.4	13.6	16.5
Al_2O_3 0.05%	6.9	10.5	14.8	18.1
Al_2O_3 0.1%	7.4	11.2	15.5	19.3
CuO 0.1%	7.2	11.0	15.1	18.9
SiO_2 0.1%	6.6	10.2	14.2	17.4

Table 1: Temperature Drop Across Cooling System (°C)

Coolant Type	25% Load	50% Load	75% Load	100% Load
Base Coolant Only	432	585	741	865
Al_2O_3 0.1%	496	648	802	938
CuO 0.1%	489	635	791	921

Table 2: Calculated Convective Heat Transfer Coefficient (W/m²·K)

Nano-coolants show improved temperature drop and heat transfer coefficient compared to base coolant. Al_2O_3 at 0.1% concentration provided the best overall performance. All nano-coolants remained stable during the tests with minimal sedimentation observed.

4.Results and Discussions

The experimental results clearly demonstrate that the addition of nanoparticles to conventional engine coolant significantly enhances the thermal performance of the cooling system. Among the nano-coolants tested—Aluminum Oxide (Al_2O_3), Copper Oxide (CuO), and Silicon Dioxide (SiO_2)—the Al_2O_3-based nano-coolant at 0.1 wt% concentration exhibited the most effective heat dissipation across all engine load conditions (Kumar, 2022).

Temperature measurements at the coolant inlet and outlet revealed a greater temperature drop for nano-coolants than for the base fluid. At full engine load (100%), the temperature drop increased from 16.5 °C with the base coolant to 19.3 °C with Al_2O_3 (0.1%). This corresponds to an approximately 17% improvement in thermal performance. The convective heat transfer coefficient followed a similar trend, increasing from 865 $W/m^2 \cdot K$ for the base coolant to 938 $W/m^2 \cdot K$ with the Al_2O_3 nano-coolant, indicating enhanced convective heat transfer due to the higher thermal conductivity of the dispersed nanoparticles (Jarrah, 2021).

CuO nano-coolants also showed significant improvement but slightly underperformed compared to Al_2O_3. SiO_2, although still more efficient than the base coolant, demonstrated relatively lower enhancement due to its lower thermal conductivity among the tested particles. The performance gain is attributed to increased surface area and improved thermal conduction paths facilitated by well-dispersed nanoparticles (Mukesh Kumar, 2018).

Additionally, no significant sedimentation or clogging was observed during the test period, indicating good dispersion stability, especially with the use of SDS as a surfactant and ultrasonication. These results suggest that nano-coolants can be effectively used to improve heat removal in internal combustion engine cooling systems, especially under high-load conditions.

5.Conclusion

The experimental investigation confirms that nano-coolants significantly enhance the thermal performance of engine cooling systems compared to conventional coolants. Among the nanoparticles tested, Al_2O_3 at a concentration of 0.1 wt% provided the highest improvement in both temperatures drop and convective heat transfer coefficient. The use of nano-coolants led to an increase in heat dissipation efficiency, particularly under higher engine loads, without causing sedimentation or flow issues during operation.

These findings suggest that nano-coolants offer a promising solution for improving engine cooling, potentially leading to better thermal management, improved engine performance, and reduced risk of overheating. Future work may include long-term stability studies, optimization of nanoparticle concentration, and testing under varying environmental conditions to support real-world applications.

References

Al-Araji, K. M. (2021). Nano-Fluids as a Coolant for Automotive Engine Radiators: Review Study. *Al-Furat Journal of Innovations in Mechanical and Sustainable Energy Engineering* , 64-78.

Arivazhagan, S. a. (2023). Experimental investigation of an automobile radiator using carbon based hybrid nano coolant. *International Journal of Thermal Sciences*.

Bargal, M. H. (2025). Thermohydraulic performance augmentation and heat transfer enhancement of automotive radiators using nano-coolants: a critical review. *Journal of Thermal Analysis and Calorimetry*, 1-53.

Dushyanthkumar, G. L. (2024). Experimental Investigation of the Enhancement of Heat Transfer Rate in Automobile Radiator Using Low Concentration Hybrid Nanofluids. *Journal of Mines, Metals and Fuels*, 1187-1202.

Gakare, A. A. (2019). Review on recent automotive experimental applications of nano coolants. *J. Nanosc. Nanoeng. & Appl*, 1-10.

Jadeja, K. M. (2023). Nanofluid as a coolant in internal combustion engine–a review. *International Journal of Ambient Energy*, 363-380.

Jarrah, H. T. (2021). Experimental investigation of Silver/Water nanofluid heat transfer in car radiator. *Journal of Mechanical Engineering and Sciences*, 7743-7753.

Kumar, V. a. (2022). Preheating Effects on Compression Ignition Engine Through Waste Heat Recovery Using THNF-Based Radiator Coolant: An Experimental Study. *Journal of Thermal Science and Engineering Applications*.

Lunga, H. C. (2023). the effectiveness of nanoparticles in coolants a state of the art. *Materials Today: Proceedings*, (pp. 1497-1500).

Mukesh Kumar, P. C. (2018). Performance Evaluation of Internal Combustion Engine by using MWCNT/Water based Nanofluid as a Coolant. *Journal of Applied Fluid Mechanics*, 15-21.

Reddy, P. P. (2019). An experimental investigation on heat transfer in automobile radiator using the reinforcement of titanium dioxide nano fluid in coolant. *International Journal of Research in Advent Technology*, 52-57.

Sahu, R. a. (2024). Computational Fluid Dynamics Investigation of Heat Transfer Efficiency in Automotive Radiators Using Nanofluid Coolants. *International Journal of Innovative Research in Technology and Science*, 32-39.

Sandhya, M. D. (2020). Hybrid nano-coolants in automotive heat transfer–an updated report. *Maejo International Journal of Energy and Environmental Communication* , 43-57.

Saxena, G. a. (2018). Nano coolants for automotive applications: a review. *Nano Trends: A Journal of Nanotechnology and Its Applications*, 9-22.

Shankara, R. P. (2020). Experimental investigation of enhanced cooling performance with the use of hybrid nanofluid for automotive application. *IOP conference series: materials science and engineering.*