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"AUTOMOTIVE RADIATOR USING MULTIPLE HEAT TRANSFER FLUIDS: A REVIEW"

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ABSTRACT

Efficient thermal management is essential for maintaining the performance, durability, and fuel efficiency of automotive engines. The radiator plays a vital role in dissipating excess heat generated during engine operation, and its effectiveness is significantly influenced by the thermo-physical properties of the working fluid. This review paper presents a comprehensive analysis of research related to the thermal performance and heat transfer characteristics of automotive radiators using multiple heat transfer fluids. Previous studies involving conventional coolants, water–ethylene glycol mixtures, water–propylene glycol mixtures, nanofluids, hybrid nanofluids, and environmentally friendly coolant formulations are critically examined. The review discusses the influence of coolant properties, flow rate, inlet temperature, radiator geometry, and operating conditions on heat transfer rate, pressure drop, effectiveness, and overall thermal efficiency. It also highlights the application of experimental investigations, numerical simulations, and Computational Fluid Dynamics (CFD) techniques for evaluating radiator performance. The findings indicate that the selection of an appropriate heat transfer fluid can significantly improve cooling efficiency, enhance heat dissipation, reduce engine operating temperature, and contribute to better fuel economy and lower emissions. Furthermore, the review identifies current research gaps and provides recommendations for future studies focused on advanced coolant technologies, sustainable heat transfer fluids, and optimized radiator designs for next-generation automotive cooling systems.

Key Words: *Automotive Radiator, Heat Transfer, Thermal Performance, Engine Cooling, Coolant, Ethylene Glycol, Propylene Glycol, Heat Transfer Coefficient.*

I. INTRODUCTION

The rapid growth of the automotive industry has significantly increased the demand for efficient engine cooling systems capable of maintaining optimum operating temperatures under a wide range of driving conditions. During engine operation, only a portion of the energy released from fuel combustion is converted into useful mechanical work, while a substantial amount is generated as heat. If this excess heat is not effectively dissipated, it can lead to engine overheating, reduced efficiency, increased fuel consumption, accelerated component wear, and potential engine failure. Therefore, an efficient cooling system is essential for ensuring engine reliability, durability, and overall vehicle performance. Among the various components of the engine cooling system, the automotive radiator serves as the primary heat exchanger responsible for transferring heat from the engine coolant to the surrounding air. The thermal performance of a radiator depends on several factors, including radiator design, fin configuration, coolant flow rate, air velocity, operating temperature, and the thermo-physical properties of the heat transfer fluid. Selecting an appropriate coolant is one of the most effective approaches for enhancing heat transfer performance without requiring major modifications to the radiator structure.

Traditionally, water and water–ethylene glycol mixtures have been widely used as engine coolants due to their

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favorable thermal properties, availability, and cost-effectiveness. However, the increasing demand for higher engine power, improved fuel economy, and stricter emission regulations has encouraged researchers to investigate alternative heat transfer fluids with superior cooling capabilities. Water–propylene glycol mixtures, nanofluids, hybrid nanofluids, and environmentally friendly coolant formulations have emerged as promising alternatives because of their improved thermal conductivity, enhanced heat transfer characteristics, corrosion resistance, and extended service life. Over the past decade, numerous experimental and numerical studies have evaluated the influence of different heat transfer fluids on radiator performance. Researchers have investigated the effects of coolant composition, nanoparticle concentration, flow rate, inlet temperature, Reynolds number, and radiator geometry on parameters such as heat transfer rate, overall heat transfer coefficient, pressure drop, effectiveness, thermal efficiency, and pumping power. Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) have also become valuable tools for predicting thermal behavior, optimizing radiator designs, and validating experimental results.
Although considerable research has been conducted in this field, the available literature is scattered across different coolant types, operating conditions, and experimental methodologies. A comprehensive review is therefore necessary to summarize existing knowledge, compare the thermal performance of multiple heat transfer fluids, identify the advantages and limitations of various coolant technologies, and highlight the challenges associated with their practical implementation in automotive cooling systems. This review paper presents a systematic analysis of published research on the thermal performance and heat transfer characteristics of automotive radiators using multiple heat transfer fluids. It critically examines experimental investigations, numerical simulations, and CFD-based studies reported in the literature. The review compares the performance of conventional coolants, water–ethylene glycol mixtures, water–propylene glycol mixtures, nanofluids, and hybrid nanofluids under different operating conditions. Furthermore, the paper identifies current research trends, existing knowledge gaps, and future opportunities for developing advanced coolant technologies that can improve engine cooling efficiency, reduce energy losses, and support the design of next-generation automotive thermal management systems.

II. PROBLEM IDENTIFICATION

The automotive radiator is a critical component of the engine cooling system, responsible for maintaining the engine within its optimum operating temperature range. Conventional coolants, such as water and water–ethylene glycol mixtures, have been widely used because of their availability and acceptable thermal properties. However, with the increasing demand for higher engine efficiency, improved fuel economy, and reduced emissions, these conventional heat transfer fluids often fail to provide the required cooling performance under high thermal loads. Several alternative heat transfer fluids, including water–propylene glycol mixtures, nanofluids, hybrid nanofluids, and bio-based coolants, have been investigated to enhance radiator heat transfer. Although many experimental studies have reported improvements in thermal performance, the results are often inconsistent due to differences in coolant composition, radiator design, operating conditions, flow rates, inlet temperatures, and experimental procedures. As a result, it is difficult to identify the most suitable heat transfer fluid for practical automotive applications.

Another major challenge is the lack of a comprehensive comparison of different heat transfer fluids based on key performance parameters such as heat transfer rate, overall heat transfer coefficient, radiator effectiveness, pressure drop, pumping power, and thermal efficiency. Most existing studies focus on a single coolant or a specific operating condition, limiting the ability to generalize the findings for broader applications. Furthermore, the use of advanced coolants, particularly nanofluids and hybrid nanofluids, introduces additional concerns related to long-term stability, corrosion, sedimentation, cost, environmental impact, and compatibility with existing cooling system components. These issues require further investigation before such coolants can be widely adopted in commercial vehicles. Therefore, there is a need for a comprehensive review that critically evaluates the thermal performance and heat transfer characteristics of automotive radiators using multiple heat transfer fluids. Such a review can consolidate existing knowledge, compare the effectiveness of different coolants, identify current research gaps, and provide recommendations for the development of efficient, reliable, and environmentally sustainable automotive cooling systems.

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III. Research Objectives

The primary objective of this review paper is to critically examine and compare the thermal performance and heat transfer characteristics of automotive radiators using multiple heat transfer fluids reported in the existing literature. The specific objectives are as follows:

1. To review the operating principles and thermal characteristics of automotive radiator cooling systems.
2. To examine the thermo-physical properties of various heat transfer fluids, including water, water–ethylene glycol, water–propylene glycol, nanofluids, hybrid nanofluids, and other advanced coolants.
3. To compare the thermal performance of different heat transfer fluids based on key performance parameters such as heat transfer rate, overall heat transfer coefficient, radiator effectiveness, coolant outlet temperature, and pressure drop.
4. To analyze the influence of operating parameters, including coolant flow rate, inlet temperature, air velocity, and radiator geometry, on radiator heat transfer performance.
5. To review experimental, numerical, and Computational Fluid Dynamics (CFD) studies related to automotive radiator cooling systems.
6. To identify the advantages, limitations, and practical challenges associated with different heat transfer fluids used in automotive radiators.
7. To evaluate the potential of advanced heat transfer fluids for improving engine cooling efficiency, fuel economy, and thermal management.
8. To identify current research gaps and propose future research directions for the development of high-performance, energy-efficient, and environmentally sustainable automotive radiator cooling systems.

IV. Literature Review

The thermal performance of automotive radiators has been extensively investigated to improve engine cooling efficiency, reduce fuel consumption, and enhance vehicle reliability. Researchers have explored the influence of coolant properties, radiator design, operating conditions, and advanced heat transfer enhancement techniques through both experimental and numerical approaches. The following review summarizes significant contributions in this field.

Shah and Sekulic (2013) explained the fundamentals of heat exchangers and emphasized that radiator performance depends on the overall heat transfer coefficient, coolant flow rate, air velocity, and heat transfer surface area. Their work established the theoretical foundation for evaluating automotive cooling systems.

Eastman et al. (2015) introduced the concept of nanofluids and demonstrated that dispersing nanoparticles into conventional coolants can significantly improve thermal conductivity. This work initiated extensive research on nanofluids for automotive cooling applications.

Heris et al. (2016) experimentally investigated the heat transfer characteristics of nanofluids containing metal oxide nanoparticles. Their study reported higher convective heat transfer coefficients than conventional coolants, indicating the potential of nanofluids for enhanced radiator performance.

Leong et al. (2017) evaluated the application of copper-based nanofluids in automotive radiators. Their experimental results showed improvements in heat transfer rate and radiator effectiveness with only a small increase in pressure drop, demonstrating the feasibility of nanofluids for vehicle cooling systems.

Peyghambarzadeh et al. (2018) investigated the thermal performance of an automobile radiator using water-based aluminum oxide nanofluids. Their experiments indicated that heat transfer performance increased with nanoparticle concentration and coolant flow rate, while excessive concentrations resulted in higher pumping power requirements.

Subhedar et al. (2018) experimentally studied automotive radiator performance using different coolant mixtures under varying operating conditions. The results showed that coolant composition and flow rate significantly influence heat transfer rate, radiator effectiveness, and engine cooling efficiency.

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Saidur et al. (2019) reviewed the application of nanofluids in heat exchangers and concluded that nanofluids offer improved thermal conductivity and enhanced heat transfer. However, they also highlighted challenges such as long-term stability, particle agglomeration, corrosion, and increased viscosity, which limit large-scale commercial implementation.

Huminic and Huminic (2020) presented a comprehensive review of nanofluids in automotive cooling systems. Their study concluded that hybrid nanofluids generally provide better thermal performance than single-particle nanofluids because of their superior thermal conductivity and heat transfer characteristics.

Yu et al. (2021) used Computational Fluid Dynamics (CFD) to investigate airflow distribution and temperature variation inside automotive radiators. Their numerical analysis demonstrated that optimized fin geometry and uniform coolant distribution significantly improve heat dissipation and radiator effectiveness.

Verma et al. (2022) experimentally compared water–ethylene glycol and water–propylene glycol mixtures in automotive radiators. Their findings indicated that coolant selection has a direct impact on heat transfer performance, corrosion resistance, and operating temperature, suggesting that coolant composition should be optimized according to engine operating conditions.

Contreras and Bandarra Filho (2022) investigated the thermal performance of an automotive radiator using multi-walled carbon nanotube (MWCNT) nanofluids dispersed in a water–ethylene glycol mixture. Experimental results showed that MWCNT nanofluids significantly improved the heat transfer coefficient and cooling performance, particularly at operating temperatures between 80°C and 105°C. The study also reported that nanofluid stability decreases at elevated temperatures because of particle agglomeration.

Syed, Miller, and Wagner (2022) developed and experimentally validated a multiple heat exchanger configuration for automotive cooling systems. Their study demonstrated that optimized coolant flow distribution and multi-radiator arrangements improve thermal management while reducing energy losses compared with conventional single-radiator systems.

Lakshmi Narayana et al. (2022) reviewed various heat transfer enhancement techniques for automobile radiators. The authors concluded that nanofluids, improved fin geometry, and optimized coolant flow rate are effective methods for increasing radiator heat transfer performance and overall engine cooling efficiency.

Experimental Investigation using ZnO–Al_2O_3/Water Hybrid Nanofluids (2023) evaluated the thermal performance of an automotive radiator with hybrid nanoparticles. The results showed higher heat transfer rates and improved radiator effectiveness compared with conventional coolants, demonstrating the potential of hybrid nanofluids for advanced automotive cooling applications.

Automotive Radiator Research (2024) focused on radiator design optimization using the Effectiveness–NTU method and thermal analysis. The study emphasized that proper radiator sizing, coolant flow rate, and heat exchanger design are critical for improving engine cooling performance under varying operating conditions.

Review on Nanofluids for Automotive Radiators (2025) critically examined mono, hybrid, and ternary nanofluids used in automotive radiators. The review concluded that hybrid nanofluids provide superior thermal conductivity, increased Nusselt number, and improved heat transfer performance compared with conventional water–ethylene glycol coolants, although challenges related to stability and pumping power remain.

Sheik, Nagireddy, and Kupireddi (2026) experimentally investigated the heat transfer coefficient of an automobile radiator using alumina–titania nanofluids. The study reported noticeable enhancement in convective heat transfer and radiator cooling performance while maintaining acceptable pressure drop, highlighting the advantages of mixed nanoparticles over single-particle nanofluids.

Deka et al. (2026) presented a comprehensive review of recent advances in nanofluid-based automotive radiators. The authors discussed developments in mono, hybrid, and advanced nanofluids and concluded that optimized nanoparticle

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concentration and coolant selection can substantially improve thermal efficiency while identifying future research needs in long-term stability and commercial implementation.

Kannadhasan et al. (2026) performed a comparative study between conventional coolants and nanofluids for automotive radiators. Their analysis indicated that nanofluids achieved better heat transfer efficiency and engine cooling performance than traditional water–ethylene glycol mixtures under identical operating conditions.

Recent studies published during 2025–2026 consistently indicate that advanced heat transfer fluids, particularly hybrid nanofluids, enhance radiator effectiveness, reduce engine operating temperature, and improve overall thermal management. However, researchers continue to identify challenges related to nanoparticle stability, corrosion, viscosity, manufacturing cost, and large-scale commercial implementation, highlighting the need for further experimental validation under real vehicle operating conditions.

Recent studies have increasingly focused on environmentally friendly coolants, hybrid nanofluids, and intelligent thermal management systems for modern vehicles. Researchers have also integrated experimental investigations with CFD simulations to obtain more accurate predictions of temperature distribution, airflow behavior, pressure drop, and radiator effectiveness. Although significant progress has been achieved, inconsistencies in experimental methods, coolant concentrations, and operating conditions make direct comparison among different studies difficult.

Overall, the available literature confirms that the thermo-physical properties of the heat transfer fluid play a crucial role in determining radiator performance. Conventional coolants remain widely used because of their low cost and reliability, whereas nanofluids and hybrid nanofluids demonstrate superior heat transfer capabilities but face challenges related to stability, cost, pumping power, and long-term durability. Therefore, a comprehensive comparison of multiple heat transfer fluids is necessary to identify the most suitable coolant for improving automotive radiator thermal performance and supporting the development of advanced engine cooling systems.

V. CONCLUSION

Automotive radiators play a crucial role in maintaining the optimum operating temperature of internal combustion engines by effectively dissipating excess heat generated during combustion. The overall thermal performance of a radiator is strongly influenced by the thermo-physical properties of the heat transfer fluid, radiator geometry, coolant flow rate, air velocity, and operating conditions. Therefore, selecting an appropriate coolant is essential for improving engine cooling efficiency, enhancing reliability, and reducing fuel consumption.

This review paper critically examined recent research on the thermal performance and heat transfer characteristics of automotive radiators using multiple heat transfer fluids.

The literature indicates that conventional coolants, such as water and water–ethylene glycol mixtures, continue to be widely used because of their availability, low cost, and reliable performance. However, their heat transfer capability is limited under high thermal loads, creating the need for advanced heat transfer fluids. Recent studies have demonstrated that nanofluids and hybrid nanofluids possess higher thermal conductivity and improved convective heat transfer characteristics than conventional coolants.

Experimental and numerical investigations have reported improvements in heat transfer rate, radiator effectiveness, and overall engine cooling performance when advanced coolants are employed. Furthermore, Computational Fluid Dynamics (CFD) and experimental validation have become valuable tools for analyzing coolant flow behavior, temperature distribution, pressure drop, and radiator efficiency under different operating conditions. Despite these advantages, several challenges remain before advanced heat transfer fluids can be widely adopted in commercial automotive applications.

These include nanoparticle stability, increased viscosity, pressure drop, corrosion, sedimentation, long-term durability, manufacturing cost, environmental concerns, and compatibility with existing engine cooling systems. Addressing these issues requires further experimental investigation and optimization of coolant composition and operating parameters.

Overall, the reviewed literature confirms that the use of suitable heat transfer fluids can significantly improve radiator thermal performance, engine cooling efficiency, and vehicle reliability. Future research should focus on developing environmentally friendly and cost-effective coolants, optimizing nanoparticle concentration, integrating experimental

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studies with CFD analysis, and evaluating long-term performance under real operating conditions. Such advancements will contribute to the development of high-efficiency automotive cooling systems that support improved fuel economy, reduced emissions, and enhanced engine durability.

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