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"EXPERIMENTAL INVESTIGATION OF THERMAL PERFORMANCE AND HEAT TRANSFER CHARACTERISTICS OF AN AUTOMOTIVE RADIATOR USING MULTIPLE HEAT TRANSFER FLUIDS"

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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

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modifications to the radiator structure.

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

The experimental investigation was conducted using a standard automotive radiator test setup to evaluate the thermal performance of different heat transfer fluids. The radiator was connected to a closed-loop circulation system consisting of a storage tank, centrifugal pump, electric heater, flow control valve, and measuring instruments. Water, ethylene glycol-water mixture, and selected nanofluids (if applicable) were used as the working fluids under identical operating conditions. The inlet temperature of the coolant was maintained at predetermined values using an electric heater, while the coolant flow rate was varied to analyze its effect on heat transfer. Air was supplied across the radiator using a controlled-speed fan to simulate actual vehicle cooling conditions. Thermocouples were installed at the inlet and outlet of both the coolant and air streams to record temperature data. The coolant flow rate was measured using a flow meter, and pressure drop across the radiator was also monitored. Experimental readings were recorded after achieving steady-state conditions for each test. The heat transfer rate, overall heat transfer coefficient, effectiveness, and thermal efficiency of the radiator were calculated using standard heat transfer equations. Finally, the thermal performance of the radiator was compared for all tested heat transfer fluids under identical operating conditions to determine the most effective coolant.

V. Result & Discussion

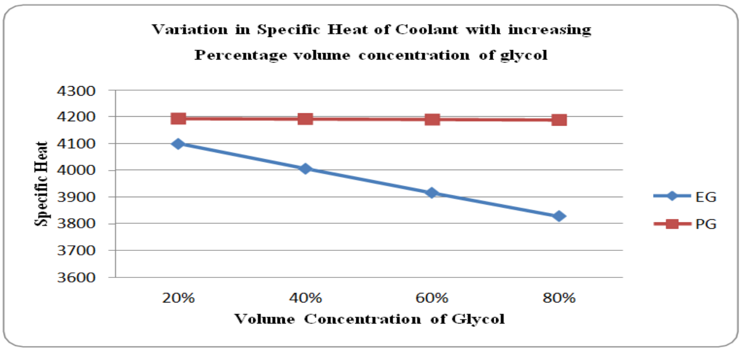

Figure 5.1 Variations in Specific Heat with % Volume Concentration of Glycol

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From the figure 5.1 above it is clearly seen that the specific heat decreases appreciably with increase in percentage volume concentration of EG where the specific heat decreases from 4099.68 J/KgK at 20% volume concentration to 3826.82 J/KgK at 80% concentration whereas there is not much drop in case of PG for which the value drops from4193.3 J/KgK at 20% to4188.38J/KgK at 80%.

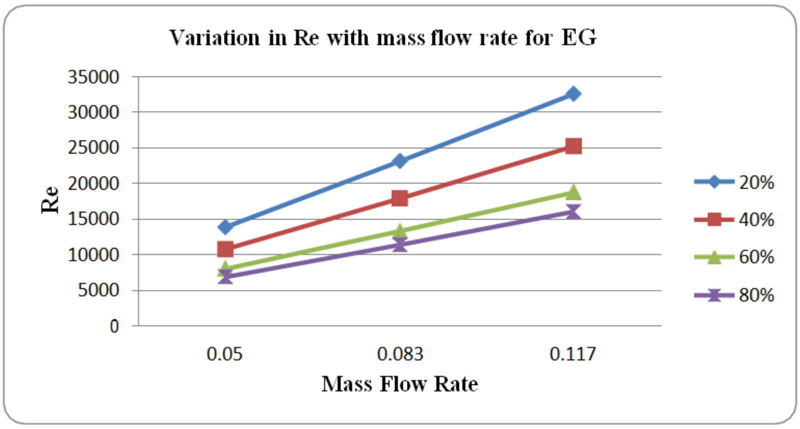

Figure 5.2 Variations in Reynolds number with mass flow rate for EG

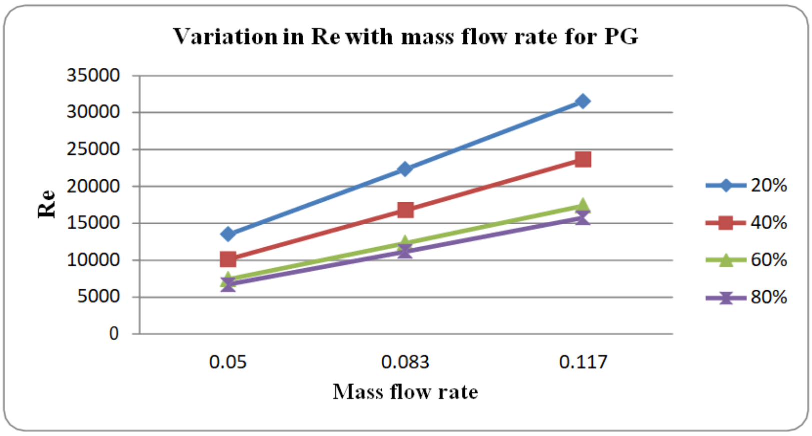

Figure 5.3 Variations in Reynolds number with mass flow rate for PG

Figures 5.2 and 5.3 shows the variation of the coolant Reynolds number with mass flow rate. During the experiment, the mass flow rate was maintained as the controlled parameter rather than the Reynolds number. The fluid density, velocity, and dynamic viscosity varied with the percentage volume concentration of glycol, resultin g in different Reynolds numbers for different coolant compositions.

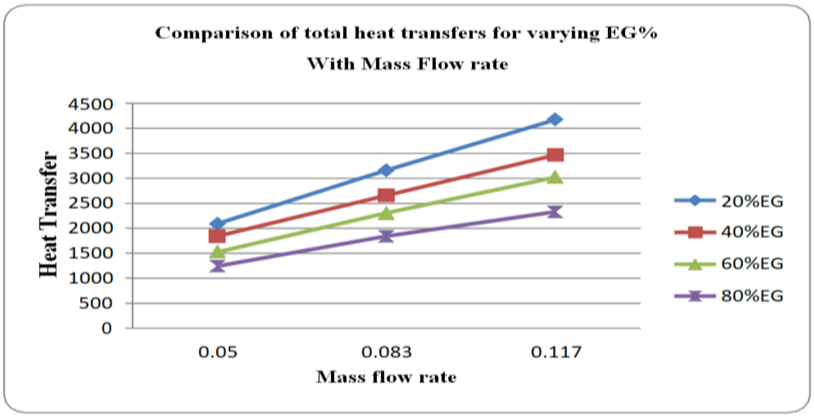

Figure 5.4 Comparison of heat transfer for varying EG % with mass flow rate

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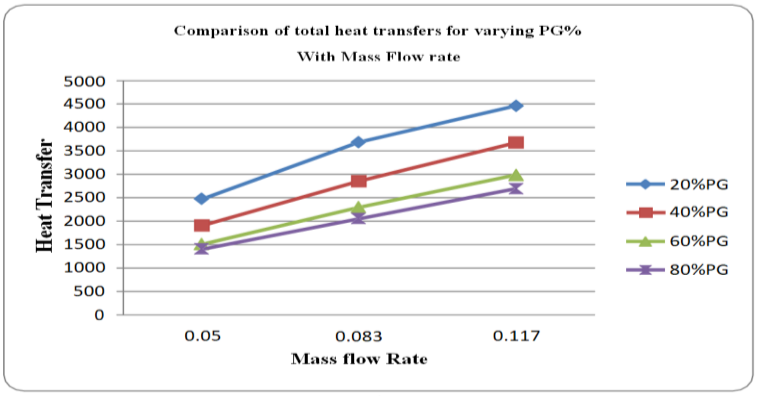

Figure 5.5 Comparison of heat transfer for varying PG % with mass flow rate

Figures 5.4 and 5.5 depict the variation of total heat transfer with mass flow rate for different coolant compositions. The comparison is based on varying coolant mass flow rates, irrespective of the corresponding Reynolds number. From the graphs, it is observed that the maximum heat transfer is obtained with 20% propylene glycol (PG) at a mass flow rate of 0.117 kg/s, whereas the minimum heat transfer is observed with 80% ethylene glycol (EG) at a mass flow rate of 0.05 kg/s. This comparison eliminates the direct influence of the Reynolds number and enables the selection of the optimum coolant composition and mass flow rate to achieve maximum heat transfer.

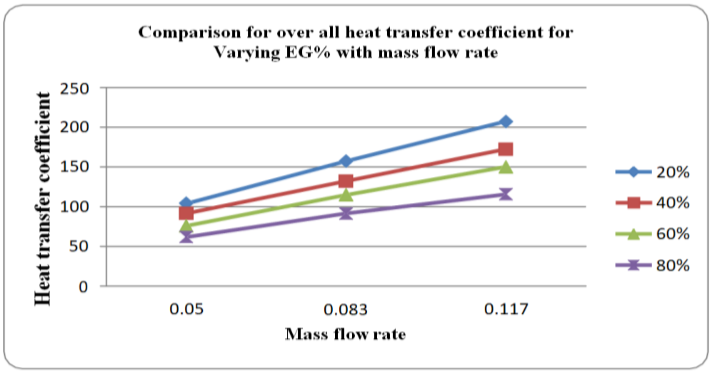

Figure 5.6 Comparison of overall heat transfer coeff. For varying EG % with mass flow rate

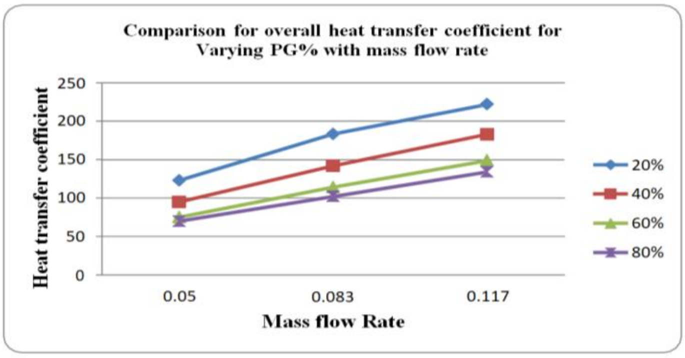

Figure 5.7 Comparison of overall heat transfer coeff. For varying PG % with mass flow rate

Figures 5.6 and 5.7 show the effect of varying mass flow rates on the coolant-side heat transfer coefficient (Hc) for ethylene glycol (EG) and propylene glycol (PG), respectively. During the experiment, the coolant mass flow rate was maintained at three different values, and the corresponding heat transfer coefficients were determined. The maximum heat transfer coefficient was observed for 20% propylene glycol (PG) at a mass flow rate of 0.117 kg/s, whereas the minimum value was obtained for 20% ethylene glycol (EG) at a mass flow rate of 0.05 kg/s.

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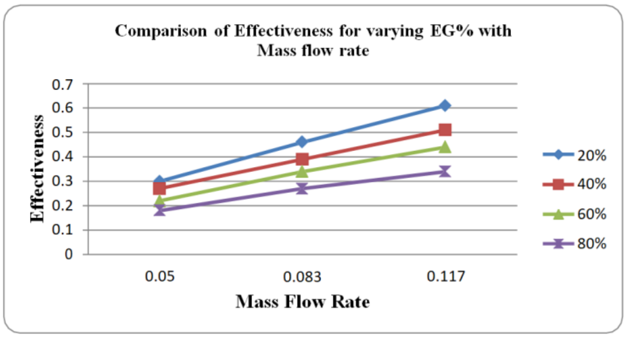

Figure 5.8 Comparison of effectiveness for varying EG % with mass flow rate

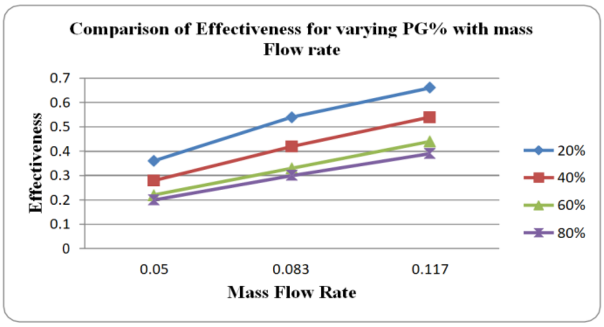

Figure 5.9 Comparison of effectiveness for varying PG % with mass flow rate

Effectiveness is directly proportional to the heat transferred. The maximum effectiveness was obtained for 20% PG at a mass flow rate of 0.117 kg/s, while the minimum effectiveness was observed for 80% EG at a mass flow rate of 0.05 kg/s.

VI. CONCLUSION

The present experimental work focused on the heat transfer characteristics, fluid flow behavior, and overall thermal performance of an automotive radiator. During the experiment, the coolant inlet temperature was maintained at **85°C**, while the air mass flow rate was kept constant. Based on the experimental investigation, the following conclusions are drawn:

1. The total heat transfer increases with an increase in coolant mass flow rate.
2. Heat transfer increases with an increase in the Reynolds number.
3. At a constant mass flow rate, heat transfer decreases with an increase in the glycol volume concentration.
4. The coolant temperature drop decreases with increasing specific heat of the coolant.
5. The coolant-side heat transfer coefficient increases with increasing mass flow rate.
6. At a constant mass flow rate, the heat transfer coefficient decreases with increasing glycol concentration.
7. Radiator effectiveness increases with increasing coolant mass flow rate.
8. At a constant mass flow rate, radiator effectiveness decreases with increasing glycol concentration.
9. Pumping power increases with increasing glycol volume concentration due to the higher density and viscosity of the coolant.

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