

Performance Assessment of Radiator Using Various Combinations of Nanofluids as Coolant

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Abstract:

Efficient thermal management is essential for maintaining the performance and reliability of automotive cooling systems. Conventional coolants such as water and water–ethylene glycol mixtures are widely used in radiators; however, their limited thermal conductivity restricts heat dissipation under increasing thermal loads. This study investigates the performance of an automotive radiator using various nanofluid combinations as alternative coolants. Nanoparticles with superior thermal properties are dispersed in a base fluid to enhance heat transfer characteristics without requiring major modifications to the radiator structure. A radiator evaluation framework was established and constructed for the purpose of analyzing the effects of various nanofluids on several important operational characteristics, including but not limited to, heat transfer rate; total heat transfer coefficient; radiator effectiveness; pressure drop; pumping power, etc. The results of the comparative analysis showed that nanofluids had the capacity to improve thermal performance through enhancing the ability of the coolant to transfer heat from the radiator to its surroundings. However, the findings also indicate that an increasing number of nanoparticles may increase resistance to flow, indicating that optimum concentrations of nanoparticles should be used to achieve maximum thermal performance at a hydraulic performance level which meets or exceeds acceptable limits. Therefore, with careful selection criteria for both types of nanofluids to use, the combination of any two types of nanofluids will greatly improve radiator performance while still achieving a hydraulic performance level that is considered acceptable, indicating that nanofluids are viable alternatives for use in developing advanced cooling systems for automotive and industrial applications.

Keywords — Nanofluids, Automotive Radiator, Heat Transfer Enhancement, Thermal Performance, Cooling System Efficiency.

I. INTRODUCTION

In order for automobile engines to achieve high levels of performance, dependability and long service life, adequate heat removal from the engine is critical. Today's automobile engines can produce

more horsepower than ever before, yet at the same time they must meet increasingly stricter emissions and fuel economy regulations; therefore, there will always be a demand placed upon engine cooling systems to remove heat generated by engines. The

removal of heat generated by internal combustion engines is performed by radiators. Radiators provide the vehicle with an efficient method to remove excess heat from the engine cooling fluids while maintaining proper engine operating temperatures. The primary limitation to the performance of traditional engine coolants (e.g., water and water/ethylene glycol mixture) is that they contain minimal amounts of high thermal conductivity material, which reduces their effectiveness for heat transfer under high thermal load conditions.

Researchers are being encouraged to research new heat transfer fluids, which would provide higher thermal performance without major design changes, to meet the demand for small, efficient cooling solutions. Nanofluids have received much attention throughout the years because of the improved thermal conductivity and heat transfer and transport properties they provide over traditional coolants. Introducing nanoparticles, such as alumina, copper oxide, and titania, into the base fluid would increase the rate of dissipated heat from the radiator and increase the effectiveness of the cooling process. In addition to thermal advantages, the use of nanofluids may lead to better engine performance and lower operating temperatures. Therefore, it is essential to conduct extensive evaluations of the various nanofluid combinations for the purpose of developing candidate formulations that provide higher thermal performance levels, while allowing for the same fluid flow and pumping characteristics as traditional coolants.

II. RELATED WORK

The usage of nanofluids is supported in enhancing the thermal characteristics of radiators by providing an increased level of heat transfer capability due to their relatively high thermal conductive properties (Gülüm et al. [1]). In addition, hybrid nanofluids can enhance these advantages through synergies between the different types of nanoparticles mixed within the same fluid; therefore, they provide additional benefits over those obtained when using only the nanoparticles present in the fluid (Tetik and Karagoz [2]). Furthermore, both Tetik and Karagoz [2] and

Hassaan [4] demonstrated through experimental investigations that the coolant containing nanoparticles outperformed traditional coolants composed of water–ethylene glycol; hence these enhanced coolants expand the range of applications for coolants in general, as evidenced by data presented from numerous other researchers in the past, such as Minh [10].

Lastly, Minh [10] also demonstrated that using Al_2O_3 –CuO hybrid-type nanofluids can provide an even greater improvement in heat transfer coefficient values compared to using solely one type of nanoparticle nanofluids, suggesting that hybrid nanofluids are viable options for use in advanced cooling systems.

III. SYSTEM ARCHITECTURE

A. Overall Design

A new radiator evaluation system is being developed to assess the (similar) characteristics of different combinations of nanofluids as coolants, with the following components: coolant reservoir/storage tank; circulation pump; piping; radiator unit; and measuring instruments. Within the system, the coolants are continuously pumped through the radiator. Therefore, because of the cooling process, the heat from the nanofluids is carried away to the air surrounding it. All nanofluids will be tested under identical conditions to quantify their effects on heat transfer rate, effectiveness, pressure drop, and input power. The design of the system allows for an objective and systematic comparison of both thermal (energy) performance and hydraulic (fluid) performance among several nanofluid combinations.

B. Module Description

- 1) Coolant Preparation Module: Responsible for preparing and storing conventional coolant and nanofluid mixtures at selected concentrations.
- 2) Circulation Module: A pump-driven system that ensures continuous and controlled coolant flow through the radiator circuit.
- 3) Heat Transfer Module: The radiator acts as the primary heat exchanger, dissipating heat from the circulating coolant to the ambient air.

4) Measurement and Analysis Module: Collects temperature, flow, and pressure data to evaluate radiator performance and compare the effectiveness of different nanofluid combinations.

5) Performance Evaluation Module: Analyzes thermal and hydraulic parameters to identify the coolant formulation that provides the best balance between enhanced heat transfer and acceptable flow resistance.

C. Methodology

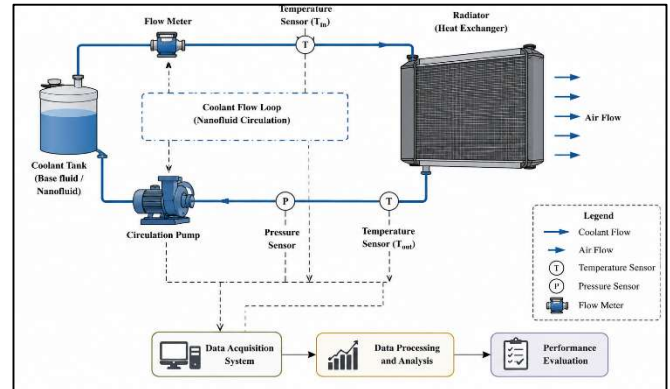
This study adopts a methodology that involves determining the thermal performance of an automotive radiator using various nanofluid combinations as coolants. The initial part of the research included an extensive survey of published literature to review the current knowledge pertaining to nanofluids used for cooling applications. This survey also allowed the selection of appropriate nanoparticles for use in radiators.

The design and manufacturing of both the radiator and the test facility will include components such as a coolant tank, circulation pump, piping network, and radiator unit. Once these components were manufactured and assembled, various combinations of nanofluids were prepared by adding the selected nanoparticles to a base fluid in proportions suitable for testing. The thermophysical characteristics of the various prepared coolant fluids were measured prior to performing the radiator tests.

Once the coolant was prepared, the fluid was circulated through the radiator while controlled operating conditions were established, and data was recorded for the following parameters: temperature at the inlet and outlet of the radiator, heat transfer rate, pressure drop (the difference between the pressure at the inlet and outlet), and effectiveness given as the ratio of amount of heat removed from the fluid flowing through the radiator and the amount of heat entering the fluid at the inlet and exiting the radiator at the outlet. The data resulting from the tests performed using nanofluid coolants were compared to data from conventional coolant tests to evaluate the performance of the radiator using a nanofluid. The data collected from the tests

will be analyzed to identify which combination of nanofluid and base fluid provided improved thermal performance of the radiator without sacrificing acceptable hydraulic performance or adversely affecting energy usage.

Fig. 1 System architecture illustrating the experimental setup for evaluating



radiator performance using various nanofluid coolants.

D. Design and 3D Modelling

A design and 3D model of the radiator performance assessment using the radiator unit are developed to have a visual representation of how the radiator performance assessment system will look before it has been fabricated. The 3D model allows for the proper location of the major components of the radiator performance assessment system, which includes the radiator unit, the coolant tank, the pump, and the piping network. The design shows how the components will be located and verifies the overall layout of the system.

The 3D CAD model was used as a guide for the fabrication and assembly of the experimental setup for the performance assessment. The 3D CAD model will also enable design changes and dimension verification to take place before the manufacturing process and to ensure the coolant circulation path and component integration will be planned out properly, which will reduce the likelihood of potential assembly errors and increase the overall reliability of the system. Fig. 2 illustrates the three-dimensional CAD model of the proposed radiator performance assessment setup.

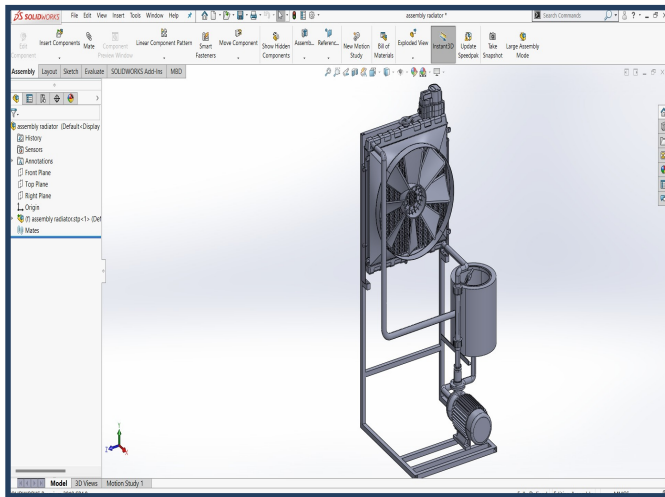


Fig. 2 Three-dimensional CAD model of the proposed radiator performance assessment system.

E. Mathematical Formulation

To evaluate the effectiveness of the various combinations of nanofluids used in cooling, standard heat transfer relations were examined. These equations enable the measurement of the cooling capacity of the radiator and also serve as a means of comparison to the thermal performance of traditional coolant fluids and nanofluid-based coolant fluids.

The thermal performance of the radiator is evaluated using the heat transfer rate and radiator effectiveness relations.

$$Q = \dot{m}C_p(T_{in} - T_{out}) \tag{1}$$

where Q is the heat transfer rate, \dot{m} is the coolant mass flow rate, C_p is the specific heat capacity of the coolant, and T_{in} and T_{out} are the inlet and outlet coolant temperatures, respectively.

$$\epsilon = \frac{Q_{actual}}{Q_{max}} \tag{2}$$

where ϵ is the radiator effectiveness, Q_{actual} is the actual heat transferred by the radiator, and Q_{max} is the maximum possible heat transfer under the given operating conditions.

These equations were used to compare the thermal performance of conventional coolants and nanofluid combinations under identical operating conditions.

IV. IMPLEMENTATION DETAILS

The evaluation of radiator operation employed an experimental arrangement made up of a radiator, coolant container, circulation pump and piping network in a closed loop; the arrangement was supported by a mild steel frame for structural strength. Several different types of nanofluids were developed and circulated through a radiator under controlled conditions. The purpose of creating the radiator evaluation system was to determine the effects of using nanofluids on heat transfer compared to conventional coolants. The total thermal and hydraulic performance of the radiator evaluation system was determined through analysis of inlet and outlet temperature, amount of heat transferred, radiator effectiveness, and pressure drop parameters. Table I presents the key components used in the experimental setup and their respective functions within the radiator performance assessment system.

TABLE I
EXPERIMENTAL SETUP COMPONENTS

Component	Purpose
Radiator	Heat dissipation
Coolant Tank	Coolant storage
Pump	Coolant circulation
PVC Pipes	Flow path
Nanofluid	Enhanced heat transfer

V. EXPERIMENTAL EVALUATION

The evaluation of the experimental set-up was performed in the laboratory using the radiator test assembly to determine how well the different combinations of coolants would perform. The complete assembly comprised of a radiator, a tank containing coolant, a pump, and a system of pipes connected in a closed loop. Several formulations of nanofluids were circulated within the radiator to evaluate how effectively they dissipated heat.

This study evaluated multiple variables on the coolant including; temperature changes, ability to transfer heat, effectiveness of the radiator, increase in pressure drop, and pumping requirements. The information collected was used to show a comparison of the thermal and hydraulic properties of the nanofluids against conventional coolants. The experimental set-up provided an experiment with practical application for the evaluation of nanofluids in automotive radiator applications as well as to determine which formulations of nanofluids would be effective at increasing the heat removal capabilities of an automotive radiator. The test methodology used allowed for consistent operating conditions between each coolant to allow for a fair evaluation of each type of coolant. Each coolant was maintained at a fixed flow rate during testing to ensure coolant flow remained stable during testing.

Observation data obtained from the test setup were used to evaluate the effect of using nanofluids on radiator performance and to examine the relationship of how the improved heat transfer qualities affect the flow characteristics of the coolant used in the study. This evaluation will provide valuable information regarding the use of nanofluid-based coolants in advanced automotive cooling systems.

The experimental design depicted in Fig. 3 was assembled as a means of determining the effectiveness of using various nanofluid coolants on the thermal efficiency of a radiator. The design of the experimental rig includes a radiator, a reservoir (for storing coolant), a pump to circulate coolant through the rig and pipes configured in a closed loop to allow for the testing of thermal performance.



Fig. 3 Photographic representation of the complete experimental system used to conduct research into the use of nanofluids as radiator coolant.

The parameters reviewed for the experimental evaluation of the Radiator System are summarized in Table II. The selected parameters will provide a comprehensive evaluation of both the thermal and hydraulic performance of the Radiator System. Each of these metrics will help evaluate the effectiveness of using nanofluid coolants under controlled operational conditions.

TABLE III
PERFORMANCE PARAMETERS EVALUATED

Parameter	Purpose
Temperature Difference	Evaluate cooling effectiveness
Heat Transfer Rate	Measure heat dissipation capability
Radiator Effectiveness	Assess thermal performance
Pressure Drop	Analyze flow resistance
Pumping Power	Determine energy requirement

VI. DISCUSSION

According to findings from an experimental evaluation study, nanofluids may provide significantly enhanced thermal performance of a radiator when compared with traditional (non-nanofluid) coolants. The enhanced heat transfer

properties of the nanofluid will provide better heat dissipation as well as increased cooling efficiency. However, increasing the concentration of nanoparticles within the nanofluid will lead to greater flow resistance through the radiator and therefore more "pumping" requirements to achieve the same flow rate.

VII. FUTURE ENHANCEMENTS

Future investigations into hybrid and multiphase systems with enhanced thermal characteristics could yield significant advancements in thermal performance through the use of sophisticated Computational Fluid Dynamics (CFD) studies, extended in-operational stability assessments of hybrid and multiphase fluids, optimally mixing the nanoparticles to achieve greater efficiencies of radiators and developing advanced evapotranspiration (EV) cooling systems for hybrid and multiphase systems.

VIII. CONCLUSIONS

In this study, performance evaluations were made for an automotive radiator with multiple types of nanofluids used as coolants. The results show that "nanofluids" have better heat transfer properties and improve radiator cooling performances when compared to traditional coolants. The experimental system built to conduct evaluations allowed for measuring all primary thermal & hydrodynamic parameters under controlled conditions. In general, results suggest that coolants based on nanofluids will allow for increased efficiencies in the use of automotive cooling systems and promote development of smaller and more energy efficient radiators.

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