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RESEARCH ARTICLE

Performance assessment of radiator using various combinations of nanofluids as coolant

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ABSTRACT

This study considers the effect of CuO (copper oxide) nanoparticles on the heat transfer performance of automotive radiators with imprint formulation while controlling the design of experiments and the factors affecting its performance. Other factors include the concentration of CuO nanoparticles, which is characterized by measuring actual thermal performance parameters such as thermal conductivity and pressure drop. The experimental design includes the configuration of the apparatus, the measuring devices and their arrangement, and the placement of thermometers and flow restrictors for efficient data collection. Externally controlled and monitored conditions include a non-restricted constant temperature space and minimal or no airflow to avoid inconsistencies in the gathered data. In this study it has been seen that with increased CuO concentrations where enhanced heat transfer was achieved, there was also a corresponding increase in flow resistance. This research justifies the need to design an appropriate experimental plan and control the measuring conditions to achieve the expected results with precision and reproducibility. This work contributes to this understanding and presents various possibilities for improving radiator performance using nanotechnology.

Keywords: heat transfer; copper oxide; nanofluids; radiator; nanoparticle concentrations; Energy efficiency

1. Introduction

The past few years have seen a growing demand for cooling systems that can work more effectively in several sectors, with such being true for the automotive, electronics, and energy systems[1]. Conventional coolants do offer a solution to the problem of heat exchange, but they fail to sustain the increased rate of thermal management that is presently being sought[2]. Nanofluids have developed as a possible improvement over all these limitations, as they are engineered fluids that add nanoparticles to the original heat transfer base fluids. These nanofluids have also shown improvement in thermal conductivity, which means enhanced heat transfer and better temperature control, thereby lowering energy use[3,4].

Compared with different nanoparticles incorporated in the preparation of the fluids for nanofluids, copper oxide (CuO) seems to be the most promising because of its superior thermal properties, low cost, and good dispersion. CuO nanoparticles help enhance the heat transfer property of fluids to an appreciable level, which makes them suitable for use in any application that requires cooling, such as in radiator systems.

This research examines the radiator system that incorporates CuO nanoparticles, specifically determined by how the various concentrations of CuO nanoparticles affect the thermal management system. The main aim is to ascertain if the use of CuO nanofluids could be utilized in the enhancement of the radiator heat removal features, which, in the case of this study, will be pictured as an increase in the efficiency of such radiators; therefore, over time reducing the heat energy consumption in the industrial and automotive sectors. This study, therefore, focuses on the practical application of CuO nanofluids in radiator optimization and other related heat transfer devices with a particular focus on variations in operating nanoparticle level and operating conditions.

The addition of CuO nanoparticles to radiator systems is a novel approach that provides a means of enhancing thermal efficiency and reducing energy consumption. Nanofluids can lower the operating temperatures of cooling systems while using a coolant with enhanced thermal conductivity, which leads to improved system performance. Improving the heat transfer characteristics, stability, and dispersion of CuO-based nanofluids is addressed in this study in relation to the size and concentration of nanoparticles and the type of base fluid. The originality of this research is that it considers only CuO nanofluids in radiator systems, which is a rather under-researched area. In addition, it evaluates the performance of CuO nanofluids for several working conditions which helps in improving cooling system technology and green engineering practices.

2. Literature Review

Tugba Tetik and Yasin Karagoz[5] investigated the efficiency of two radiator systems, one using a water/ethylene glycol (70:30) based Al2O3-SiO2-TiO2 nanofluid and the other using a water/EG mixture. The results demonstrated that the primary factors contributing to the enhancement of heat transfer are the flow velocity and the nanoparticles incorporated into the base liquid in varying quantities.

Malla, Hossain and Islam[6] used a vertical heat radiator cavity in the cascading lattice Boltzmann simulation of non-Newtonian and Newtonian mixing nanofluids with varying thermophysical parameters. The results have practical applications for improving radiator systems in cars, which play a key role in keeping engine temperatures stable.

Malika, Sonawane and Sharifpur[7] used mononanoparticle-based and hybrid nanofluids in their research work. Water and ethylene glycol were used during experimental fluids in the work. Studies reveal that hybrid nanofluids were better coolants than mononanoparticle systems.

Kumar and Hassan[8] investigated how nanoparticle concentration, flow rate, and frontal air velocity affect automobile radiator performance with CuO-MgO-TiO_2 aqueous ternary hybrid nanofluid. The volume concentration of nanoparticles is 0.1%–0.5% was used during experimentation. Flat tube radiator fluid inlet temperature, coolant flow rate, and frontal air velocity were examined. The base fluid had a 46% lower coolant side heat transfer coefficient than 0.5% hybrid nano-coolant. Nano-coolant requires 1.71 times base fluid pumping power. Additionally, the overall heat transfer coefficient is correlated.

Jibhakate et al.[9] used fins to increase radiator cooling in their research work. This work analyzes a radiator employing water-based Al_2O_3 + CuO hybrid nanofluid and ethylene glycol (EG) to increase heat exchange. The base fluid contained 30% EG, 0.1% Al_2O_3 nanoparticles, and 0.1% CuO. ANSYS 17 was used to simulate and evaluate a cooling circuit in transient mode. The study found that hybrid nanoparticles increase heat transmission over base fluid.

Ganeshkumar et al.[10] had used Kigelia Africana leaves synthesized, and they are stably dispersed in deionized water and used in automobile radiators. Thermal properties of deionized water-based nanofluids were measured in their experimentations. The convective heat transfer coefficient of an automobile radiator was also reported. They found that the Nusselt number and friction factor were enhanced by raising the concentration and mass flow rate.

Kumar et al.[11] carried out experimental investigation on hybrid nano-coolant in a louvered finned radiator for automobile cooling. MWCNT-SiO_2-Ethylene Glycol-Water hybrid nanofluid has been used as the coolant in their research work. They have studied the effect of coolant flow rate and external airflow in the automobile radiator. They found that the maximum cooling power for nano-coolant was 40% higher than its base fluid.

Mastafizur et al.[12] had used hybrid nanofluids with solid particles smaller than 100 nm to improve performance in their research work. Experimental results show that Al_2O_3-MWCNT/radiator coolant hybrid nanofluid with thermal conductivity, viscosity, and density increased with nanoparticle volume percentage. Also, it has been found that as the temperature rises, viscosity and density decrease.

3. Experimental Setup

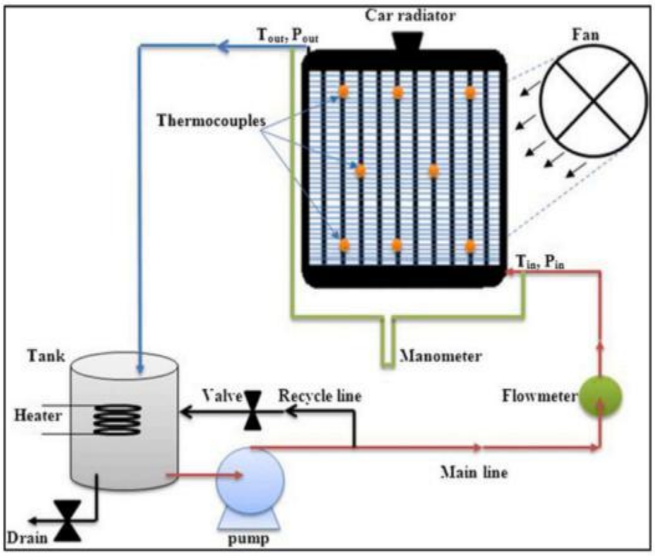

Figure 1: Schematic diagram for the experimental setup.

Figure 1 shows setup is used for analyzing the Performance Assessment of radiator using various combinations of Nanofluids as Coolant. The setup consists of listed following devices:

Equipment Used:

- Radiator: An ordinary automotive radiator typical of having many tubes and fins to facilitate heat dissipation.
- Fan: A Fan is placed in such a way that it provides the required air flow across the radiator for cooling of the nanofluid.
- Pump: A centrifugal pump meant for working with CuO nanofluids distributing it at a given flow rate.
- Flowmeter: A CuO nanofluid flow control device used to control flow of CuO nanofluids.
- Thermocouples: Fitted at the inlet (T_{in}), outlet (T_{out}), and even inside the radiator to monitor any changes in temperatures.
- Manometer: Pressure is taken at different locations to see pressure losses which may be attributed to the high liquid density of the CuO nanofluids.
- Tank with Heater: A tank fitted with a heater is used to heat the CuO nanofluid before the experiment and during the experiment to keep the temperature constant.

Installation Steps:

- Step 1: Fill the tank with the CuO nanofluid prepared earlier. Ensure proper filling to avoid cavitation.
- Step 2: Connect the pump to the main line to circulate the CuO nanofluid through the radiator.
- Step 3: Install the flowmeter along the main line to monitor the flow rate accurately, as CuO nanofluids may have higher viscosity.
- Step 4: Place thermocouples at the inlet, outlet, and strategic points across the radiator. Connect them to a data logger for continuous temperature recording.
- Step 5: Install a manometer to measure pressure at the inlet and outlet points of the radiator.
- Step 6: Position the fan in front of the radiator, ensuring that it maintains a consistent airflow across the radiator's surface.
- Step 7: Set up a recycle line with a valve to control the flow rate and regulate circulation.

Operating Procedure:

- Initiate System: Initially, the pump and pipelines must be demonstrated to alleviate any vapour lock on the CuO nanofluid.
- Thermal Regulator: The heater should be employed to implement the working temperature of the CuO nanofluid, as needed.
- Control of Flow Rate: To maintain the prescribed flow rate, alter the recycling line valve along with pump speed and ensure that it does not exceed the limits of the flowmeter.
- Observational Study: Record inlet and outlet temperature and pressure values in order to determine the efficiency of the radiator with CuO nanofluids.

Radiator

Radiators serve as warm exchangers planned to exchange warm vitality from one medium to another for cooling or warming purposes. They discover far-reaching applications in automobiles, buildings, and electronic frameworks. Despite the term "radiator," these gadgets essentially encourage warm exchange through convection instead of warm radiation. An early frame of a radiator for building space warming can be followed back to the Roman hypocaust. In any case, Franz San Galli, a Prussian-born Russian businessman dwelling in St. Petersburg, is credited with designing the warming radiator around 1855. Galli got a radiator obviously in 1857. In any case, Joseph Nason, an American, created a simple radiator in 1841 and secured a few U.S. licenses related to hot water and steam heating frameworks (See **Figure 2**).

Within the domain of inside combustion motors, radiators play a basic part in cooling. They are commonly found in automobiles, piston-engine flying machines, railroad trains, bikes, stationery creating plants, and other applications utilizing inside combustion motors. To cool the motor, a coolant circulates through the motor square, retaining warm. The warmed coolant at that point enters the radiator's channel tank, found either on the beat or along one side, sometime recently spreading over the radiator center through tubes to reach another tank on the inverse conclusion. As the coolant streams through the radiator tubes towards the inverse tank, it discharges much of its warmth to the tubes, which, in turn, exchanges the warm to the balances situated between each push of tubes. These balances productively scatter the warm to the encompassing discussion. The joining of balances essentially increments the contact surface range of the tubes with discussion, upgrading warm trade productivity. Whereas the radiator regularly does not diminish the coolant temperature to surrounding discuss levels, it adequately cools the coolant to avoid motor overheating.

Table 1. Specifications of the radiator used for the research.

Parameter	**Specifications**
Fluid inlet temperature	
Core height	0.30 m
Core width	0.30 m
Core depth	0.015 m
Tube sizes	0.6 cm × 25 cm
Fin type	Ruffled
Fin thickness	0.01 cm
Tube arrangement	Staggered

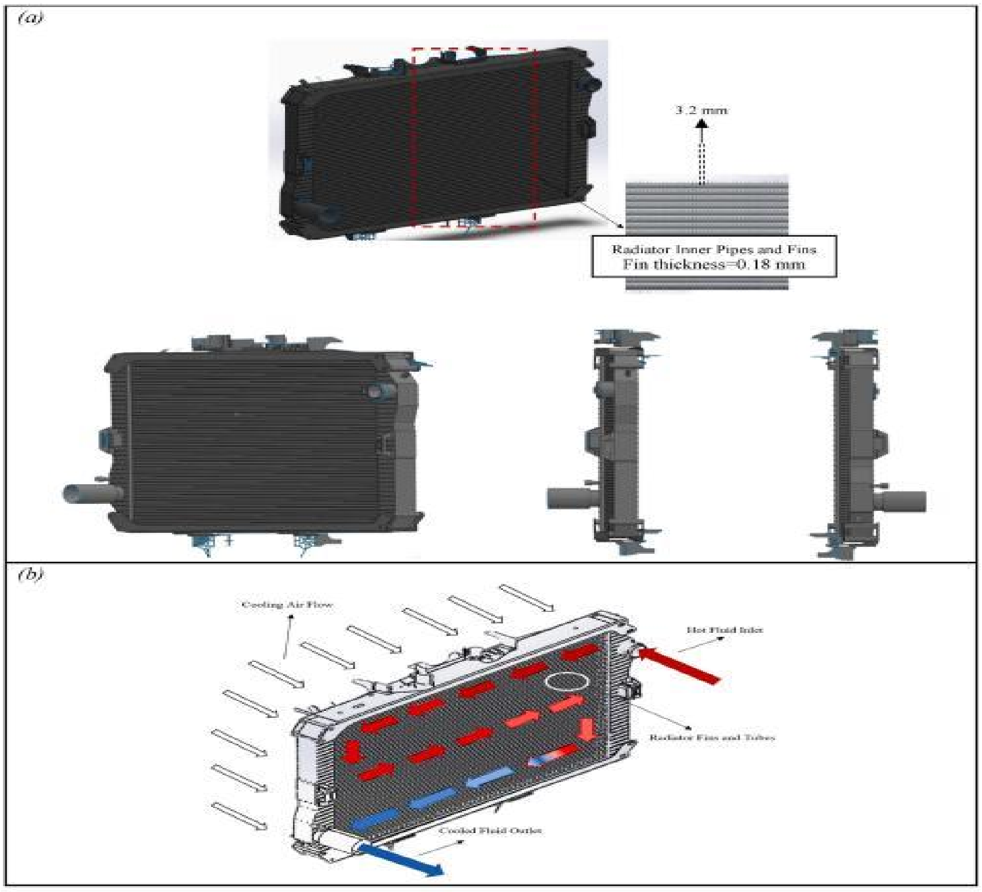

Figure 2. Schematic diagram of the radiator used.

Nanofluid

A nanofluid could be a liquid containing nanoparticles, which are particles of greatly little measure. These liquids are basically designed suspensions of nanoparticles inside a base liquid, with common base liquids counting water, ethylene glycol, and oil. Nanoparticles utilized in nanofluids are regularly composed of metals, oxides, carbides, or carbon nanotubes. Nanofluids have interesting properties that render them profitable over different warm exchange applications, such as microelectronics, fuel cells, pharmaceutical forms, and hybrid-powered motors. They discover utility in motor cooling and vehicle warm administration, residential refrigeration, chillers, and warm exchangers, as well as in pounding, machining, and evaporator vent gas temperature diminishment forms. Eminently, nanofluids display improved warm conductivity and convective warm exchange coefficients compared to their base liquids.

Here it has further Discussed about selection of Nanoparticles Copper oxide (CuO), Nanofluid Preparation and its Process

Materials:

- Nanoparticles: Copper oxide (CuO) nanoparticles are selected for their excellent thermal conductivity and stability, making them ideal for heat transfer applications.
- Base Fluid: We use water, ethylene glycol, or a combination of both to enhance the dispersion and thermal conductivity when mixed with CuO.
- Surfactants: To avoid the agglomeration of CuO nanoparticles, we opted to include surfactants such as SDS or CTAB, based on the suspension's stability.

Nanofluid Preparation Process:

- Weigh the dispersion: Provide CuO nanoparticles evenly, typically between 0.1% and 2% of the total water content of the base. Dissolve the nanoparticles in the base water separately.
- Ultrasonic agitation: Using an ultrasonic homogeniser or bath, disperse the CuO nanoparticles for about 45-60 minutes. A critical step that aims to enhance consistency by agitating the samples is overcoming the agglomerates.
- Stirring: A magnetic or mechanical stirrer must be employed to continuously stir the nanofluid so that it remains homogeneous.
- Stability Testing: The stability of the nanofluid is monitored for 24 hours after which sedimentation if any, is assessed. If sidedness is detected, the process of ultrasonication is repeated or surfactants are recommended.

Impact of Different CuO Nanofluid Concentrations on System Performance

The addition of varying amounts of CuO nanoparticles in the nanofluid alters significant parameters in the system such as the heat transfer rate the fluid, viscosity, and thermal conductivity. To see it more closely:

1. Heat transfer rate:

- Low Concentration (0.1–0.5 wt%): For CuO nanofluids in this range, one can expect a mild improvement in the thermal conductivity of the fluid, hence a corresponding moderate improvement in heat transfer. At the lower concentration of particles, agglomeration, and sedimentation are less likely, and thus, a steady flow is induced.
- Moderate Concentration (0.5–1.0 wt%): This improvement, of course, comes at a threshold concentration of thermal conductivity of cheap heat transfer fluids like radiators. However, this increase in viscosity may increase the flow resistance, making it necessary to use a more powerful pump.

High Concentration (>1.0 wt%): The thermal conductivity enhancement observed by increasing concentration extends the possibilities of heat removal. However, this also increases the risk of agglomeration and sedimentation, which can affect the flow and even cause a blockage. In addition, the increase in viscosity might reduce the flow rate, which in turn leads to negative effects on cooling efficiency. Most of the results have shown that increasing the concentration of CuO leads to better heat transfer, as depicted in the graph through a larger temperature drop across the radiator ($T_{out} - T_{in}$). However, it is important to note that these higher concentrations can lead to increased pressure drops and lower flow rates which may affect efficiency if the pump is not capable of overcoming the losses.

2. Temperature of System Components:

- As the CuO concentration increases, the temperature change at the radiator becomes more extreme. It is due to the high temperature, which causes the nanofluid to absorb more heat and allows heat to return from the radiator.
- Increased CuO concentration also tends to increase the pump temperature due to the rapid effects of thermal resistance and thermal viscosity and any materials in contact with the fluid.

Thermodynamics of Heat Transfer with CuO Nanofluids

The thermodynamic impact of utilizing CuO nanofluids in a radiator system can be outlined as follows:

1. Enhanced Thermal Conductivity:

- The incorporation of CuO nanoparticles boosts the thermal conductivity of the base fluid, thanks to CuO's high thermal conductivity. This improvement enables the nanofluid to absorb and transfer heat more efficiently, thereby increasing the heat transfer rate and cooling performance.

2. Improved Convective Heat Transfer:

- Nanoparticles induce micro-convection currents within the fluid through Brownian motion, which enhances the convective heat transfer coefficient. The effect becomes more pronounced with higher nanoparticle concentrations, although it is limited by the increase in viscosity at elevated concentrations.

3. Increased Viscosity and Flow Resistance:

- While a higher concentration of CuO enhances thermal conductivity, it also leads to increased viscosity. This rise in viscosity results in greater flow resistance, necessitating more energy from the pump and potentially reducing the flow rate if the pump's capacity is exceeded. It is essential to find a balance between concentration and viscosity to optimize heat transfer without placing excessive strain on the pump.

Solving Agglomeration and Stratification Issues

Agglomeration (clumping) and stratification (settling) of CuO nanoparticles present significant challenges in nanofluids. These issues can affect fluid stability and diminish heat transfer efficiency. Here are some strategies to address these problems:

- Use of Surfactants:

Incorporating surfactants such as SDS, CTAB, or oleic acid into the nanofluid can be beneficial. These substances generate a repulsive force around the nanoparticles, which helps to minimize agglomeration. Experimental Recommendation: Introduce a surfactant at a concentration of approximately 0.1–0.5 wt% of the total nanofluid volume and conduct stability tests to verify that the selected surfactant effectively inhibits agglomeration without compromising heat transfer characteristics.

- Ultrasonic Agitation:

Employing an ultrasonic homogenizer for prolonged agitation can assist in breaking apart any clusters of nanoparticles and ensuring an even distribution of particles within the base fluid. Procedure: Carry out ultrasonic agitation for 45–60 minutes prior to each experiment or whenever stratification is detected. This treatment improves stability by dispersing clumps and reducing particle size.

- pH Adjustment:

Modifying the pH can influence the surface charge of CuO particles, which may help decrease agglomeration through electrostatic repulsion. A slightly acidic or basic environment (depending on the coating of the nanoparticles) can enhance stability. Procedure: Test pH adjustments within the range of 6 to 8 and monitor the dispersion stability. It can be achieved by adding small quantities of acid or base while stirring continuously.

- Periodic Recirculation or Mixing:

For long-term storage, it is advisable to periodically stir or recirculate the nanofluid to prevent settling and maintain an even distribution of particles. Procedure: Set up a recycle line with a valve to allow for periodic stirring of the nanofluid without the need for ultrasonic treatment each time.

4. Methodology

To use nanofluids as coolants in vehicle radiators, an exact framework is major. From the start, select reasonable nanoparticles (e.g., metals, metal oxides, carbon-based materials) and base fluids (e.g., water, ethylene glycol). Set up the nanofluids through either a two-step system (mixing and a short time later dispersing nanoparticles) or a one-step method (joining clearly in the fluid), ensuring change using surfactants or pH control. Depict the nanofluids for particle size, thickness, thickness, warm conductivity, unequivocal power, and security. Set up an exploratory test seat repeating a vehicle radiator system equipped with sensors to evaluate temperature, stream rate, and strain drop to survey execution estimations like force move coefficient, pressure drop, and cooling capability. Research data to smooth out nanoparticle obsessions and types, reviewing both power move improvement and energy adequacy. Direct long-stretch durability and steady quality tests, considering environmental and security ideas. Finally, increment to demonstrate development and field testing in real vehicles, carrying out a monetary assessment to ensure cost-reasonability stood out from conventional coolants.

Utilizing nanofluids as coolants in vehicle radiators includes a deliberate way to deal with planning, getting ready, and assessing the exhibition of nanofluids to guarantee they improve warm properties. Here is a complete philosophy:

Determination of Nanoparticles and Base Liquids

Nanoparticles:

- Material: Normal materials incorporate metals (e.g., copper, silver), metal oxides (e.g., alumina, silica, titania), and carbon-based materials (e.g., graphene, carbon nanotubes).
- Size and Shape: Nanoparticles ordinarily range from 1 to 100 nm in size. Shape (round, barrel shaped, and so on) additionally influences warm conductivity.
- Fixation: Commonly, 0.1-5% volume part of nanoparticles is utilized. Higher focuses can prompt expanded consistency and potential obstructing.

Base Liquids:

- Normal base liquids incorporate water, ethylene glycol, propylene glycol, and oil.

Preparation of CuO Nanofluids

CuO nanoparticles were created through a chemical precipitation method. To produce these nanoparticles, copper sulfate ($CuSO_4$) was combined with sodium hydroxide (NaOH) in an aqueous solution. After synthesis, the nanoparticles were washed, dried, and characterized using techniques like X-ray diffraction (XRD) and transmission electron microscopy (TEM) to verify their size, shape, and crystallinity. Nanofluids were then prepared by dispersing the synthesized CuO nanoparticles into a base fluid, which is usually water or ethylene glycol, at different concentrations (for example, 0.5%, 1%, and 2% by weight. To make sure that the nanoparticles are evenly distributed in the base liquid, an ultrasonicator was utilized during the dispersion process. The instability of the nanofluids was also checked visually through zeta potential measurements and dynamic light scattering (DLS). Thus, it was assured that there was not much aggregation of the nanofluids over time.

Nanofluids Assessment

The ready evidence of nanofluids also underwent an evaluation of some thermophysical properties including:

- Conductivity:

A thermal conductivity meter was used to determine the heat transfer properties of the CuO nanofluids at different concentrations and temperatures.

- Viscosity:

A viscometer was instrumental in ascertaining the viscosity of the nanofluids in order to establish the effect of nanoparticle dispersion on the flow properties of the fluid.

- Particle Size Distribution:

DLS technique was adopted in the analysis of the nanoparticles size and distribution in the base fluid in order to correlate its influence of heat transfer characteristics.

Arrangement of Nanofluids

• Selection of Base Fluid:

Based on the specific application choose any one of the base fluids such as water, ethylene glycol or oil. Water is the preferable option in most cooling systems.

• Synthesis of CuO Nanoparticles:

Methods:

There are Various ways which can be used to synthesize CuO nanoparticles chemical precipitation, sol-gel, hydrothermal techniques to mention a few. One such method is that of TN-chemical precipitation which is most often used for preparing CuO nanoparticles.

Chemical Precipitation:

First make a solution of copper sulfate CuSO4 in distilled water and take in a beaker. Then a base such a s sodium hydroxide NaOH or ammonium hydroxide is used to precipitate $Cu(OH)_2$. Lastly the $Cu(OH)_2$ prec ipitate is then converted into CuO nanoparticles by heating it in a furnace or an oven at a temperature range o f 300 to 600^0C.

Scattering Methods:

• Two-step Technique: Nanoparticles first are mixed and then dispersed in the base liquid using ultrasonication or mechanical mixing.

• One-step Technique: Nanoparticles are simply added in the base liquid, which helps in better dispersion and stability. Adjustment:

• Introduction of surfactants or control of the pH is used to prevent agglomeration and enhance the degree of dispersion.

Portrayal of Nanofluids

Actual Properties:

- Molecule Size Circulation: Use of techniques such as different light scattering (DLS) or transmission electron microscopy (TEM).
- Thickness: Estimated utilizing a viscometer to guarantee the ease of nanofluids.
- Thickness: Estimated utilizing a densitometer.
- Warm Conductivity: Estimated utilizing a warm conductivity meter or laser streak investigation.

Explicit Intensity Limit: Estimated utilizing Differential Examining Calorimetry (DSC).

Security Investigation:

- Zeta likely estimations to evaluate the steadiness.
- Visual review and sedimentation tests after some time.

Test Arrangement for Execution Assessment

Radiator Test Seat:

- System: Reduced size of vehicle cooling system with radiator, siphon and power source.
- Instrumentation: thermocouples, current meters and strain sensors for quantifying temperature, current rate and stress drops.

Execution Measurements:

- Heat Move Coefficient: Ascertain utilizing temperature estimations and realized heat input.
- Pressure Drop: Measure across the radiator to guarantee it stays inside OK cutoff points.
- Cooling Productivity: Contrast and ordinary coolants under comparative circumstances.

Information Examination and Advancement

Heat Move Improvement:

- Analyze the intensity move paces of nanofluids with traditional coolants.
- Dissect the impacts of various nanoparticle focuses and types.

Energy Proficiency:

- Assess the general energy utilization, taking into account both siphon power (because of consistency) and intensity evacuation productivity.

Long haul Testing and Unwavering quality

Strength Tests:

- Direct long haul testing to survey the dependability and execution of nanofluids under cyclic warming and cooling conditions.
- Assess any potential for erosion or debasement of radiator materials.
- Natural and Wellbeing Contemplations:
- Survey the natural effect of nanoparticles in the event of spillage.
- Guarantee consistence with wellbeing norms for taking care of and removal of nanomaterials.

Increasing and Field Testing

Model Turn of events:

- Foster a model radiator utilizing the streamlined nanofluid plans. This model ought to be intended to work under true circumstances. Direct field tests in real vehicles to approve lab discoveries and guarantee pragmatic relevance.

Financial Investigation:

- Play out a money-saving advantage investigation contrasting the utilization of nanofluids and customary coolants. Consider factors, for example, producing expenses, taking care of and stockpiling prerequisites, support costs, and the potential for further developed eco-friendliness because of better cooling. **Figure 3** shows the flowchart of the current research work.

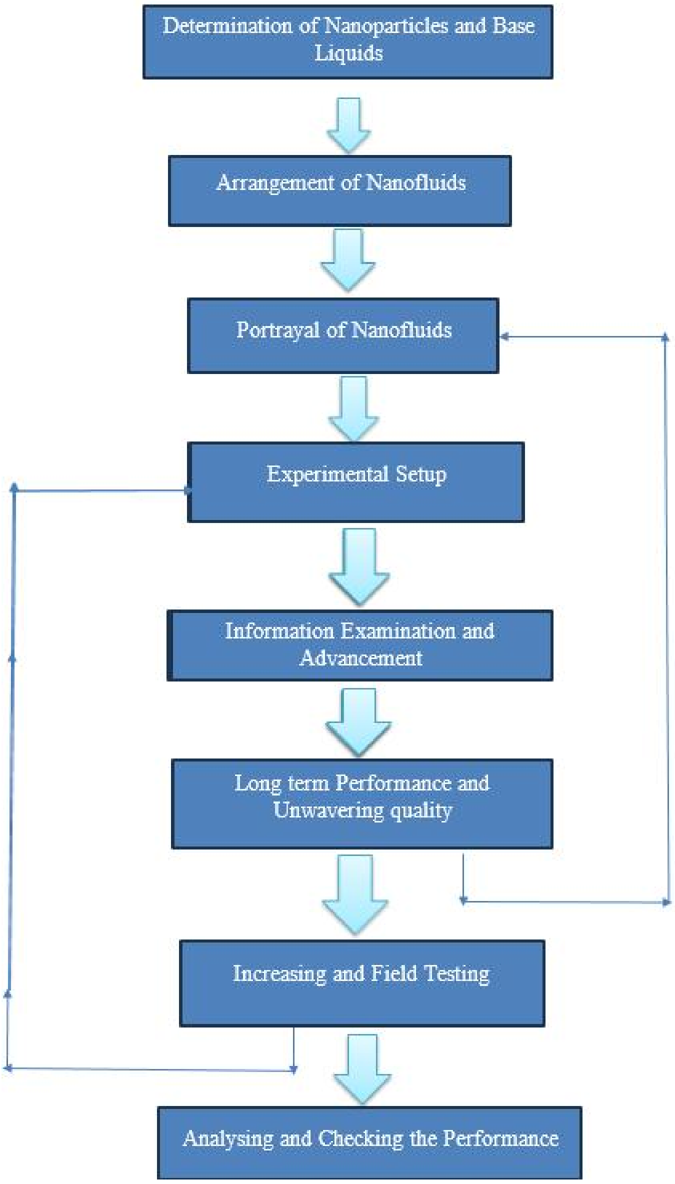

Figure 3. Flow chart for the research work.

Utilizing nanofluids as coolants in vehicle radiators offers possible advantages in upgrading warm execution and further developing energy proficiency. Nonetheless, careful regard for arrangement, portrayal, and testing is urgent to guarantee their commonsense feasibility and long-haul, unwavering quality in-car applications.

5. Result and Discussions

Table 2. Reading of water, antifreeze and concentration of nanofluids coolants in this research work.

Type of Coolant	Flow Rate (LPH)	Inlet Temp. (T_{in}) (^0C)	Outlet Temp. (T_{out}) (^0C)	Exp. $\Delta T = (T_{in} - T_{out})$ (^0C)
Water	150	45.1	42.2	2.9
	200	44	41.6	2.7
	250	43.6	40.2	3.4
Antifreeze	150	45	41.4	3.6
	200	44.4	41.2	3.2
	250	43	39.2	3.8

1% CuO	150	45.1	39.9	5.2
	200	44.2	39.5	4.7
	250	43.4	39.1	4.3
2% CuO	150	46	39.9	6.1
	200	45.3	39.6	5.7
	250	44.5	39.2	5.3

This table presents the experimental results for the cooling performance of different types of coolants, including water, antifreeze, and CuO-based nanofluids at two different concentrations (1% and 2% CuO). The coolant flow rate was varied (150, 200, and 250 LPH), and the corresponding inlet and outlet temperatures, as well as the temperature difference (ΔT), were recorded.

- **Flow Rate (LPH):** This column lists the different coolant flow rates used during the experiments, representing the volume of coolant flowing through the radiator system per hour.
- **Inlet Temperature (T_{in}) (°C):** This column shows the temperature of the coolant as it enters the radiator system.
- **Outlet Temperature (T_{out}) (°C):** This column shows the temperature of the coolant as it exits the radiator after heat dissipation in the system.
- **Experimental ΔT (°C):** This column represents the temperature difference between the inlet and outlet ($\Delta T = T_{in} - T_{out}$), which is used to evaluate the heat transfer performance of each coolant. A higher ΔT indicates more effective heat dissipation.

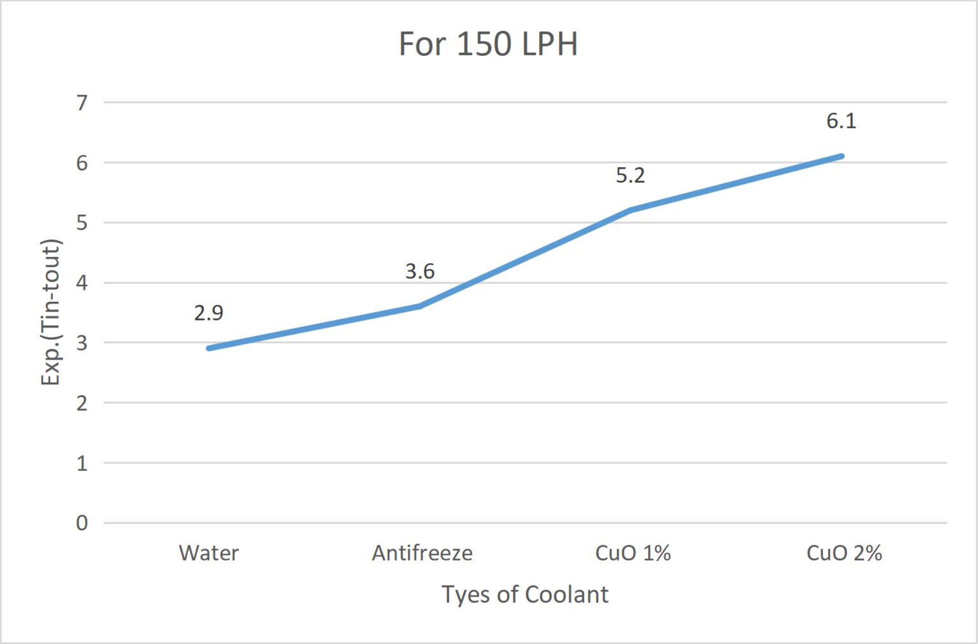

Figure 4. Variation of temperature difference for all type of nanofluids used for a fixed 150 LPH.

Figure 4 shows the flow rate at 150 LPH. The types of Coolant are water, anti-freeze, CuO 1%, and CuO 2%. It shows the resultant Exp. ΔT are 2.9 of water, 3.6 of anti-freeze, 5.2 of CuO 1%, and 6.1 of CuO 2%, indicating the increment.

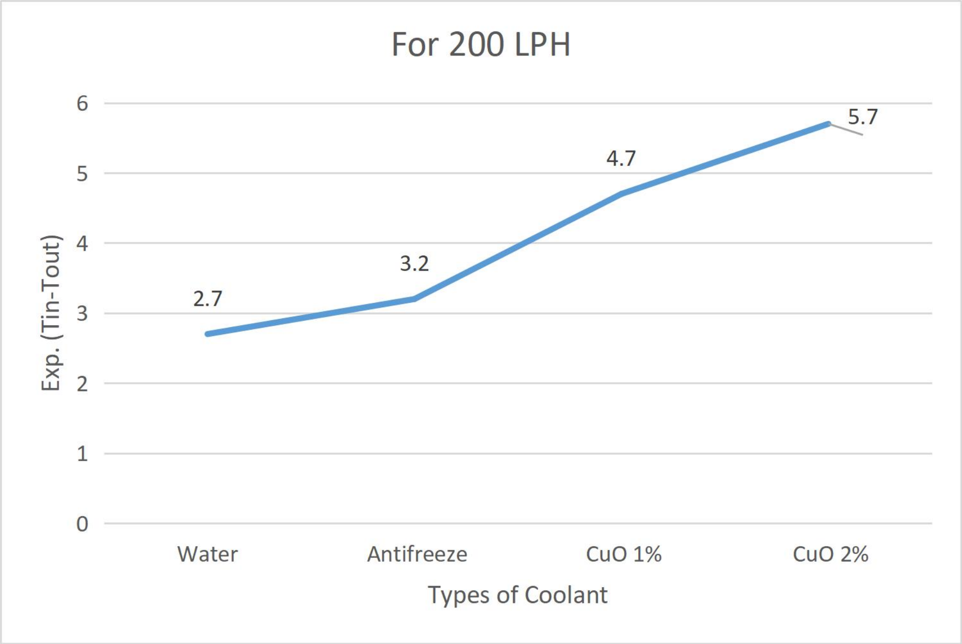

Figure 5. Variation of temperature difference for all type of nanofluids used for a fixed 200 LPH

Figure 5 shows the flow rate at 200 LPH. The types of Coolants are water, anti-freeze, CuO 1%, and CuO 2%. It shows the resultant Exp. ΔT are 2.7 of water, 3.2 of anti-freeze, 4.7 of CuO 1%, and 5.7 of CuO 2%, indicating the increment.

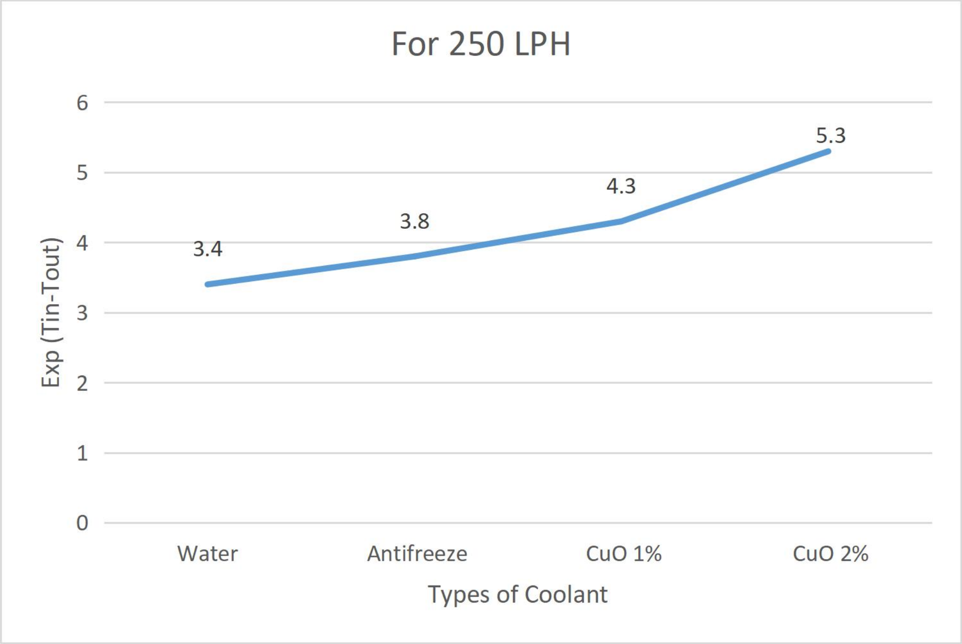

Figure 6. Variation of temperature difference for all type of nanofluids used for a fixed 250 LPH.

Figure 6 shows the flow rate at 250 LPH. The types of Coolants are water, anti-freeze, CuO 1%, and CuO 2%. It shows the resultant Exp. ΔT are 3.4 of water, 3.8 of anti-freeze, 4.3 of CuO 1%, and 5.3 of CuO 2%, indicating the increment. **Figure 7** shows the combined effects of flow rates and temperature differences for all combinations.

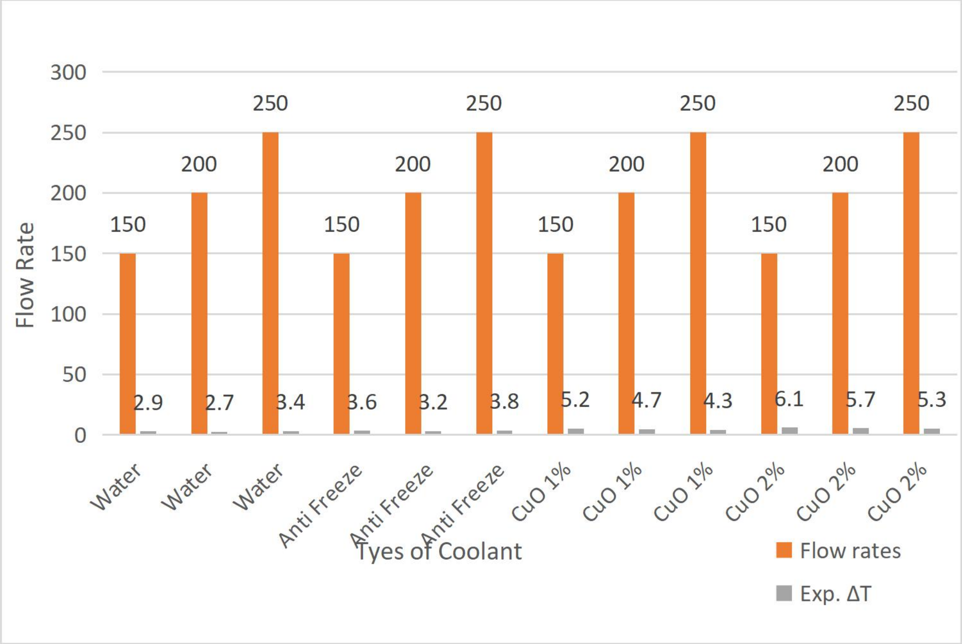

Figure 7. Combined effects of flow rates and temperature differences for all combinations

It is observed that the coolant with the highest temperature drop (ΔT) was the 2% CuO nanofluid, with values reaching up to 6.1^{0}C at a flow rate of 150 LPH, indicating superior heat transfer performance compared to both water and antifreeze. Furthermore, the 1% CuO nanofluid was able to exhibit more effective cooling than both water and antifreeze, particularly at higher moderated flow rates. In general, the observed temperature variations indicate that CuO nanofluids can exhibit better cooling performance, especially at high concentration ranges, which makes them a good substitute for conventional cooling systems.

- Water:

The difference in temperature (ΔT) for water is registered in the range of 2.7°C up to 3.4°C based on the flow rate. At low flow rates (150 LPH), the maximum ΔT reaches 2.9°C, whereas at high flow rates (250 LPH) it is 3.4°C. It means that water can take more heat when the flow rates considered are higher. It is predictable because, in high flow rates, a higher volume of water is allowed to contact the heat source, making it more effective in heat absorption.

- Antifreeze:

There is a greater difference in temperature for the case of antifreeze compared to water, with values in the range of 3.2°C and 3.8°C, respectively. For example, at 250 LPH, the value of ΔT is 3.8°C, which reveals the fact that antifreeze can absorb more heat than plain water. This enhancement can be a result of the presence of chemical additives in antifreeze, which improves the heat conduction or thermal capacity of antifreeze components compared to water only.

- 1% CuO Nanofluid:

1% CuO nanofluid gives a noticeably higher ΔT than water and antifreeze as well. The ΔT is 5.2°C at 150 LPH and then gradually decreases to 4.3°C at 250 LPH. The increase in temperature difference with 1% CuO can be linked to the enhanced thermal conductivity of the nanofluid. CuO nanoparticles, known for their high thermal conductivity, improve the heat transfer performance of the base fluid (water). However, the ΔT decreases at higher flow rates due to the reduced residence time of the nanofluid with the heat source, limiting heat absorption opportunities.

- 2% CuO Nanofluid:

The 2% CuO nanofluid shows even better performance than the 1% CuO nanofluid, with temperature differences ranging from 5.3°C to 6.1°C. At 150 LPH, the ΔT reaches 6.1°C, and even at 250 LPH, it remains relatively high at 5.3°C. The increased concentration of CuO results in further enhancement of the nanofluid's thermal conductivity, leading to improved heat transfer properties compared to both 1% CuO and traditional coolants (water and antifreeze).

Upgraded Warm Conductivity

- Copper oxide nanoparticles have fundamentally higher warm conductivity than water. At the point when scattered in the water, even in little fixations like 1% or 2% by weight, they considerably work on the warm conductivity of the base liquid. It permits the coolant to retain and move heat more productively from the motor to the radiator.
- Heat Move Productivity and Heat Transfer Productivity

Heat Move Productivity measures how effectively a heat transfer system, like a radiator, moves heat from the heat source to the heat sink. This concept encompasses the entire process, looking not just at the speed of heat transfer but also at factors such as energy losses, pump efficiency, and system resistance. In essence, it evaluates the system's overall ability to transport heat from one location to another, considering both the heat absorbed and the energy used to circulate the fluid. Heat Move Productivity, in this case, looks at the overall ability of the car radiator system to remove heat from the engine coolant and dump it into the ambient, considering the work done by other factors such as pumps, fans, and heat exchangers.

On the other hand, Heat Transfer Productivity only looks at the heat exchange effectiveness at a specific location in the system like the surface geometry where the nanofluid is applied on the radiator tubes. It assesses heat transfer across an interface over an area in terms of a limited zone, usually revolving around a heat transfer coefficient, on a zone surface area, and its temperature difference ($W/m^2 \cdot K$). This explains how effective the nanofluid will be in facilitating heat transfer and is associated with the thermal conductivity and the flow of the nanofluid.

For example, using a CuO nanofluid can boost Heat Transfer Productivity due to its enhanced thermal conductivity, allowing more heat to transfer from the fluid to the radiator tubes and thereby improving the cooling effect.

Soundness and Fixation

- 1% CuO: At this focus, the coolant shows a striking improvement in warm properties without fundamentally expanding the thickness of the liquid. This equilibrium guarantees that the coolant can stream effectively through the radiator and motor parts without causing unnecessary wear on the siphon or different pieces of the cooling framework.
- 2% CuO: Expanding the fixation to 2% further upgrades the warm conductivity and intensity move limit. It additionally builds the consistency of the coolant, which may marginally influence the stream qualities, and the energy expected to siphon the coolant through the framework.

Functional Contemplations

- Scattering and Soundness: Guaranteeing that CuO nanoparticles stay very much scattered and stable inside the coolant combination is critical. The collection of nanoparticles can diminish the viability and may cause obstructions inside the radiator and motor entries.
- Similarity and Security: The coolant combination should be viable with the materials utilized in the motor and radiator to forestall erosion and wear. Moreover, the ecological and well-being effects of utilizing nanoparticles should be considered.

Maintenance

- Utilizing CuO nanoparticle-upgraded coolants requires customary checking and support. The fixation and scattering of nanoparticles ought to be checked intermittently to guarantee ideal execution and to forestall potential issues connected with molecule settling or agglomeration.
- Consolidating CuO nanoparticles at 1% and 2% fixations in water as a coolant in radiators essentially works on warm conductivity and intensity move productivity. While the 2% fixation offers more prominent warm advantages, it should be offset with contemplations of expanded thickness and potential support difficulties. This cutting-edge coolant definition can prompt better motor execution and life span by keeping up with ideal temperatures more really than ordinary coolants.

Experimental Design:

It is the first and perhaps the most important phase where the objectives var, variables, and approaches are specified. For example, an experiment on heat transfer enhancement of nanofluids would require appropriate selection of the number of nanoparticles, base fluid, the configuration of a radiator to be studied, arranged thermocouples, flow meters, and other apparatus. Well-planned design is critical in the efficient testing of the research hypothesis, minimizing errors, and enhancing the replicability of the experiment.

Reduction of Measurement Environment Influencing Factors:

It involves all externally and internally imposed constraints that affect the accuracy and reliability of measurements. Some of these measures are ambient temperature, humidity, air movement around the radiator, and instrument calibration. In heat transfer studies, for instance, the slightest change in variable room temperature or adjusted fans putting different airflow styling around the specimens can greatly affect cooling performance levels. Hence, the data collected can never be the same. It is very important to either control these aspects or at least keep them in check and factor them in to avoid producing results that do not correlate to the actual performance of the nanofluid.

Data Result:

The term "data results" refers to the last part of the experiment in which the design and measurement conditions are combined to yield a result. In the heat transfer experiment, several aspects, such as temperature differentials, flow rates, and pressure drops, are affected by the test setup, such as CuO nanoparticle concentration and the spatial flow path, as well as the external conditions. Therefore, with the knowledge of the design and the control of the clearest factors, it becomes easier to analyze the results, which can further lead to discussing the thermal efficiency and conductivity of the nanofluids.

Logical Correlation

It is because the experimental design provides a guide on how data should be collected and the extent to which measurements are to be taken. The measurement setting is another variable that adds concern to those measurements since it is difficult to completely block all disturbances and biases that may influence the data collected. To make sound conclusions, the design must. However, the factor in organizational issues causing these disturbances and integrate them into the design in a way that their impacts are mitigated or totally removed. Then, the last data results are due to both the conditions designed and those that are outside the control of the experiment, and therefore, their approach must consider such aspects. It integrates design, internal and external environmental factors, and outcomes, enabling acquiescence of findings, consistency of practices, and enhancing the robustness of the evidence supported by the conducted experiment.

6. Discussion:

- **Effect of Flow Rate:**

Generally, there is an inversely proportional relationship between flow rate and temperature difference. For common coolant media, i.e., water and anti-freeze, the trend continues as temperature differences increase with the flow rate. It shows that as more coolant flows over the heat source, the ability of the fluid to absorb heat increases. Nevertheless, this growth is not as marked as the case when it comes to cooling with CuO nanofluids.

In the case of the nanofluids (1% and 2% CuO), the ΔT grows smaller with a higher flow rate. It was to be expected because, since less heat is transferred at higher flow rates, the coolant spends a shorter time in contact with the heat source. Nevertheless, even at high flow rates, CuO nanofluids are still much better than water or antifreeze.

- **Effect of CuO Concentration:**

The level of CuO is very necessary in enhancing the heat conducting ability of the nanofluid. The 2% CuO nanofluid is always better than the 1% nanofluid, demonstrating the effect of nanoparticle concentration. It is because the more the number of nanoparticles present in the base fluid, the enhanced the heat transfer process due to more interactions between the particles and the fluid, hence increasing the thermal conductivity value.

- **Cooling Efficiency Studies:**

CuO nanofluids, used for cooling applications, display a better cooling performance than both water and antifreeze. Even though antifreeze does better than water in containing heat, the level of enhancement associated with CuO nanofluids is significantly higher making them good for radiators and other cooling systems which require very high transfer of heat.

- **Recommendations for Use:**

The friction effect has been reduced by using nanofluids to maintain good heat transfer performance, and that is why they are recommended for heat transfer applications, especially when efficiency is of great importance. 2% CuO nanofluid has led to great performance. However, attention should be drawn to the more expensive and complicated preparation of nanofluid, which might affect some practical applications of proposed chillers. The increased effectiveness of cooling may come at the cost of shorter stability of the nanofluid.

In summary, accommodating factors of heat in CuO nanofluids is much more effective than that of common coolants of heat exchangers, especially at higher concentrations of nanoparticles. This technology gives them a high potential to enhance the cooling systems and the radiators.

7. Conclusions

This study gives a complete examination of the presentation upgrade of radiators utilizing different mixes of nanofluids as coolants. The exploratory and recreation results exhibit that the combination of nanofluids fundamentally works on the warm execution of radiators contrasted with ordinary coolants. Key discoveries include:

- Enhanced Heat Transfer: Nanofluids show predominant warm conductivity, prompting further developed heat move productivity. The presentation of the radiator was found to increment with the centralization of nanoparticles but with unavoidable losses at higher focuses.
- Ideal Nanoparticle Determination: Among the different nanofluids tried, specific nanofluid combinations showed the most encouraging outcomes about warm scattering and general radiator

effectiveness. It proposes that the decision of nanoparticles assumes a basic part in streamlining radiator execution.

- Economic and Environmental Considerations: While nanofluids offer significant execution benefits, their financial and ecological effects should be painstakingly assessed. The expense of nanoparticle unions and potential ecological worries related to their utilization ought to be weighed against the presentation gains.
- Future Extension: Further exploration is prescribed to investigate the drawn-out steadiness and potential wear impacts of nanofluids on radiator materials. Also, the improvement of practical and harmless to the ecosystem nanofluids could upgrade their business suitability.
- All in all, the utilization of nanofluids as coolants in radiators addresses a promising progression in warm administration frameworks. Be that as it may, the determination of proper nanoparticle types and focuses, alongside contemplations for cost and manageability, is urgent for amplifying the advantages of this innovation.

Conflict of interest

The authors declare no conflict of interest.

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