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Improving Automotive Radiator Performance through Nanofluid-based Heat Transfer Enhancement Coupled with Pipeline Incorporation of Phase Change Materials

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Abstract: Automotive radiator efficiency plays a pivotal role in the overall performance and sustainability of internal combustion engines. This research explores a novel approach to enhance heat transfer in automotive radiators through the synergistic use of nanofluids and the incorporation of phase change materials (PCMs). The nanofluids, consisting of copper oxide (CuO) or aluminum oxide (Al2O3) nanoparticles dispersed in a paraffin wax matrix, offer a dual mechanism for heat transfer improvement.

The first aspect of the study involves the formulation and characterization of nanofluids with optimized ratios of CuO or Al2O3 nanoparticles in paraffin wax. These nanofluids exhibit enhanced thermal conductivity, ensuring efficient heat dissipation in the radiator. The choice of nanoparticles aims to harness their intrinsic thermal properties for improved performance.

The second facet involves the integration of phase change materials directly into the radiator pipelines. Paraffin wax, chosen for its phase-change characteristics, acts as a latent heat storage medium. This addition serves a dual purpose: regulating temperature fluctuations within the radiator and absorbing excess heat during high-load conditions, thus preventing overheating.

Experimental investigations will include a comprehensive analysis of heat transfer coefficients, pressure drops, and thermal stability of the nanofluid-PCM composite. Computational models will be employed to predict and optimize the fluid flow and heat transfer characteristics within the radiator system.

The outcomes of this research hold promising implications for the automotive industry, offering a sustainable and energy-efficient solution to enhance radiator performance. The integration of nanofluids with phase change materials not only contributes to improved heat transfer efficiency but also addresses thermal management challenges in internal combustion engines, ultimately promoting a more environmentally friendly and reliable automotive cooling system.

Keywords: Automotive Radiator, Heat Transfer Enhancement, Nanofluid, Phase Change Materials, CuO Nanoparticles, Al2O3 Nanoparticles, Paraffin Wax.

I. INTRODUCTION

Modern automobile engineering relies heavily on efficient heat management as it is essential to achieving the best possible vehicle performance, lifespan, and sustainability. The radiator is a vital part of this thermal control system; its job is to dissipate extra heat that the engine produces. For this reason, water-based engine coolants have been used historically. However, new approaches to improving the heat transfer efficiency of traditional coolants have been made possible by developments in nanotechnology.

Because of their high surface area-to-volume ratio and nanoscale particle size, nanofluids engineered suspensions of nanoparticles in base fluids offer remarkable thermal characteristics. The thermal conductivity and heat capacity of the coolant may be greatly increased by incorporating certain nanoparticles into the fluid. These improvements might completely transform thermal management the radiator's capacities, hence improving the overall effectiveness and performance of vehicle cooling systems.

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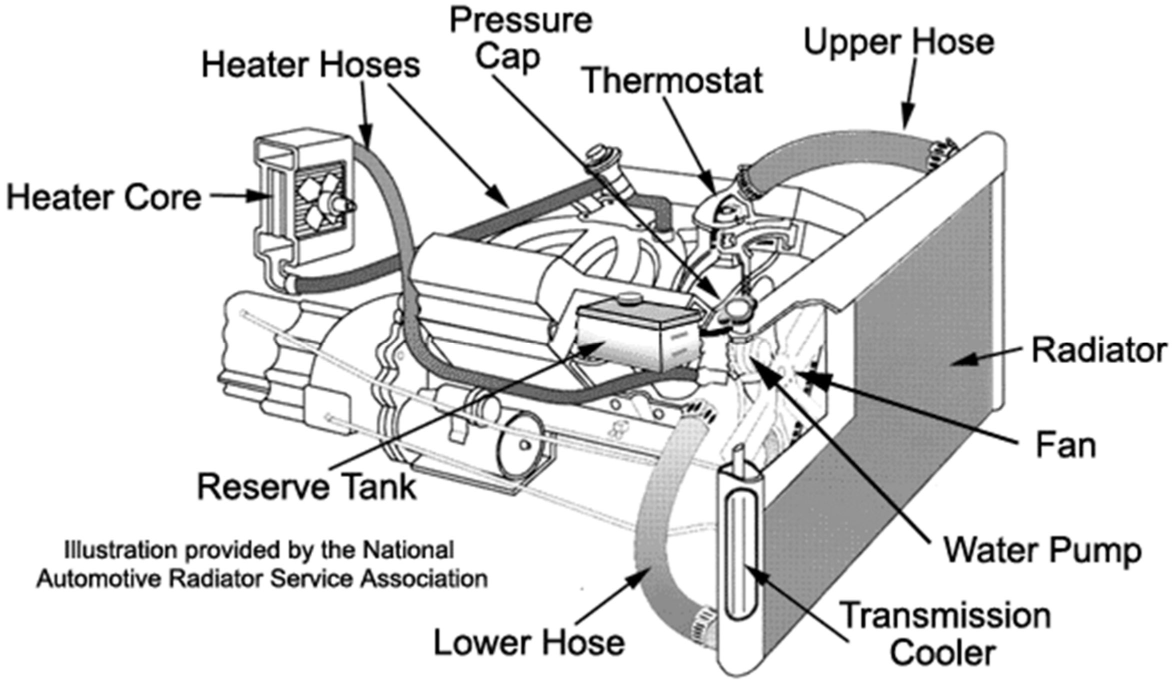

Figure 1: Typical car radiator

A. Radiator

A radiator is a type of heating appliance that is commonly used in buildings to distribute heat around a space and create comfort and warmth. Radiators are widely used in residential buildings, workplaces, and other structures. They are made of different materials and designs. Hot water or steam is circulated across a network of pipes in a radiator's fundamental operation, and the heated water or steam is subsequently released into the surrounding area.

Figure 2: Radiator

B. Radiator cap

Radiators are renowned for being effective and long-lasting. Convection, the action of warm air rising and cold air sinking, is how they function. There is a flow of heated air in the room as a result of the hot water or steam in the radiator warming the air around it and causing it to rise. In areas with harsh winters, radiators are a typical and efficient way to keep a pleasant temperature indoors.

Figure 3: Radiator cap

C. Working and Types Radiator

1) The engine coolant, a mixture of water and antifreeze, circulates through the engine and absorbs heat generated during combustion.
2) The hot coolant is then directed to the radiator, typically located at the front of the vehicle.
3) The radiator consists of a series of tubes and fins. The tubes carry the hot coolant, and the fins increase the surface area for effective heat exchange.
4) As the hot coolant flows through the tubes, heat is transferred to the radiator fins. Airflow, either from the vehicle's movement or assisted by an electric fan, facilitates heat dissipation.
5) The transfer of heat from the coolant to the air causes the coolant to cool down.
6) The now-cooled coolant returns to the engine to absorb more heat, and the process repeats to maintain the engine at an optimal temperature.

D. Fuel Cell System Cooling

Proper cooling is essential for maintaining the optimal operating temperature of a fuel cell system. Fuel cells operate most efficiently within a specific temperature range, and overheating can reduce their performance and longevity. Here's how cooling is achieved in a fuel cell system:

Figure 4: Cooling in a Fuel.

E. Cooling Techniques

Cooling techniques are employed in various systems and applications to manage and dissipate heat effectively. Here are some common cooling techniques used in different contexts.

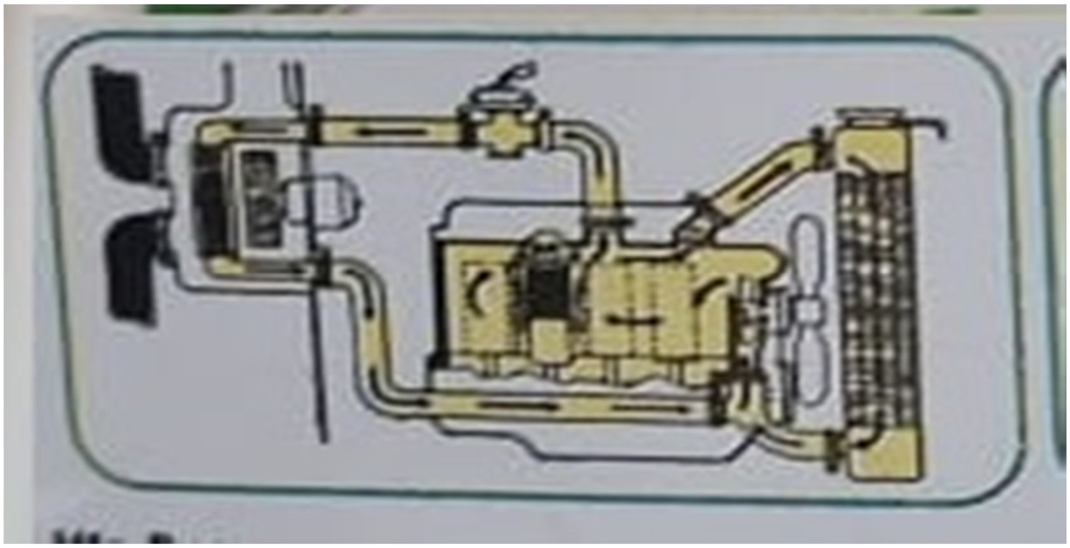

Figure 5: flow of Cooling Strategies

F. Benefits

1) The nanofluid's enhanced thermal properties significantly improve heat transfer efficiency compared to conventional coolants, ensuring the engine remains within optimal operating temperatures.
2) By efficiently dissipating excess heat, the engine can maintain peak performance, leading to improved fuel efficiency and reduced emissions.
3) Effective heat management extends the engine's lifespan by preventing overheating and minimizing thermal stress on engine components.
4) The use of nanofluids contributes to a greener environment by optimizing energy usage and reducing the overall carbon footprint of the vehicle.

G. Water pump

A water pump in a vehicle's engine is a critical component that ensures the continuous circulation of coolant, preventing engine overheating and maintaining optimal operating temperatures. Typically mounted on the engine and connected to the crankshaft by a belt or chain, the water pump operates through a centrifugal pumping mechanism.

Figure 6: water pump

The continuous circulation of coolant facilitates the transfer of heat from the engine components to the radiator, where the heat is dissipated. The water pump's mechanical seal prevents coolant leakage, ensuring its efficiency. Some modern vehicles feature electric water pumps for precise control. Regular maintenance, including checks for leaks and belt wear, is crucial for the water pump's reliable function, preventing potential engine damage due to overheating.

H. Radiator

The study's radiator, which is shown in Figure 7, is in line with the typical design used in MARUTI SWIFT cars in real-world PARAASH ENTERPRISES (A.S. Auto Hub). Lightweight aluminium, which was selected for its advantages of decreased weight and increased corrosion resistance, makes up the majority of its composition. This material selection supports the goal of improving the radiator's longevity and efficiency for the best possible performance within the car.

Figure 7.1 Radiator

Figure 7.2 Coolant Tank

The coolant tank seen in Figure 7.2 was constructed using steel sheet as the fabrication material. The reason for this decision was that steel can tolerate high temperatures while being relatively light, which outweighs the weight advantages of cast iron. Because the coolant tank may operate between 0°C and 150°C, steel is a good material to use in this situation.
The pipes shown in Figure 8 required materials that could resist high temperatures. Because they could withstand high temperatures, plastic pipes and rubber hose pipes were chosen for the system.
A cast iron coolant pump, designed to function well in high temperatures and withstanding thermal stresses, was used in. The operating method entails utilising a belt system arrangement to drive the pump, hence enabling its efficient operation within the system.

Figure 8: Water Pump

Fig. 9 illustrates the usage of switches from Anchor business, which is renowned for their dependable performance, in this configuration. The wooden box that encloses the electrical panel offers protection and organisation. Sturdy heavy-duty cables have been used to prevent failures and guarantee system stability.

Figure 9 Electrical Panel or Electrical Motor

The system's diameter reducer, which is necessary to keep the mass flow rate at its ideal level, is shown in Fig. 10. This part is essential to controlling the dynamics of flow.

Figure 10 Diameter Reducer

A coil-shaped heating element with a 3 KW capacity is used for heating, as shown in Fig 11. This heating element help s the system achieves the appropriate temperature conditions

Figure 11 Heating Element

Thermocouples, as shown, are used to detect temperature. Both the coolant temperature and the air temperature are measured by these instruments. The coolant temperature is measured using a thermocouple, which has a temperature range of 40°C to 120°C, while the air temperature is measured using an analogue thermometer.

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Specification of Experimental Setup

Table 1 Specification of testing parameters

Year	2011
Manufacturer	Maruti Swift
Model Range	Rigid passenger car M1
Engine Capacity	1197cc
Engine Types	5MT/4AT
Number of Cylinder	4/DOHC
Engine Firing Order	1-3-4-2
Compressor Ratio	9:8:1
Thermostat Opening	5 Liter Of Water
Ignition Timing Basic BTDC	BS6/75PS
Maximum Torque	4200rpm/114Nm

II. RESULT AND DISCUSSION

1) Case 1: Using Al2O3+Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 26 March 2023)

As of March 26, 2023, adding Al2O3 nanoparticles to the coolant in an automobile coolant tank is a novel way to improve the coolant's thermal conductivity and cooling effectiveness. The coolant's heat transfer characteristics should greatly increase as a result of the dispersion of Al2O3 nanoparticles, maximising the automobile engine's overall cooling performance.

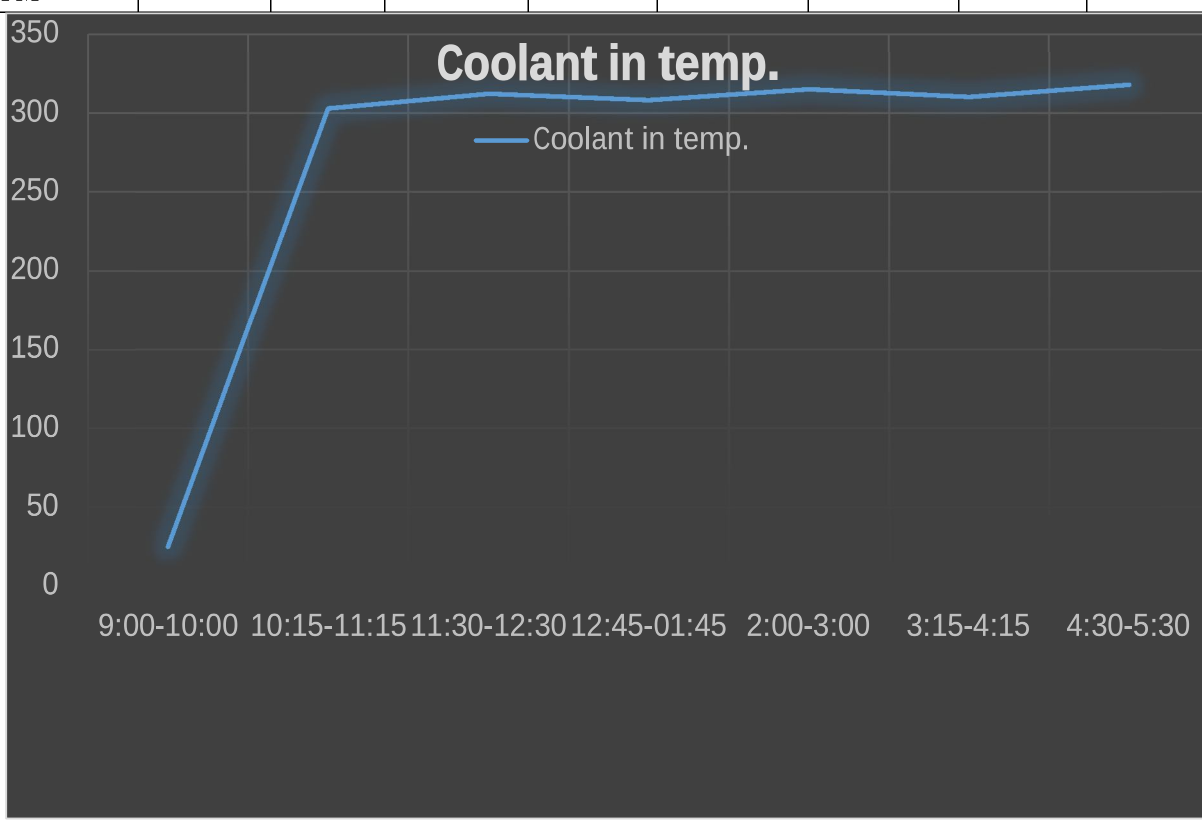
Al2O3 nanoparticles are used in car coolant tanks to absorb engine heat to a maximum and remove the largest amount of heat from the radiator in comparison to regular coolant. The coolant temperature reaches a maximum of 3210C after the engine process and a minimum of 360C after the radiator process. This is too advantageous for regular coolant.

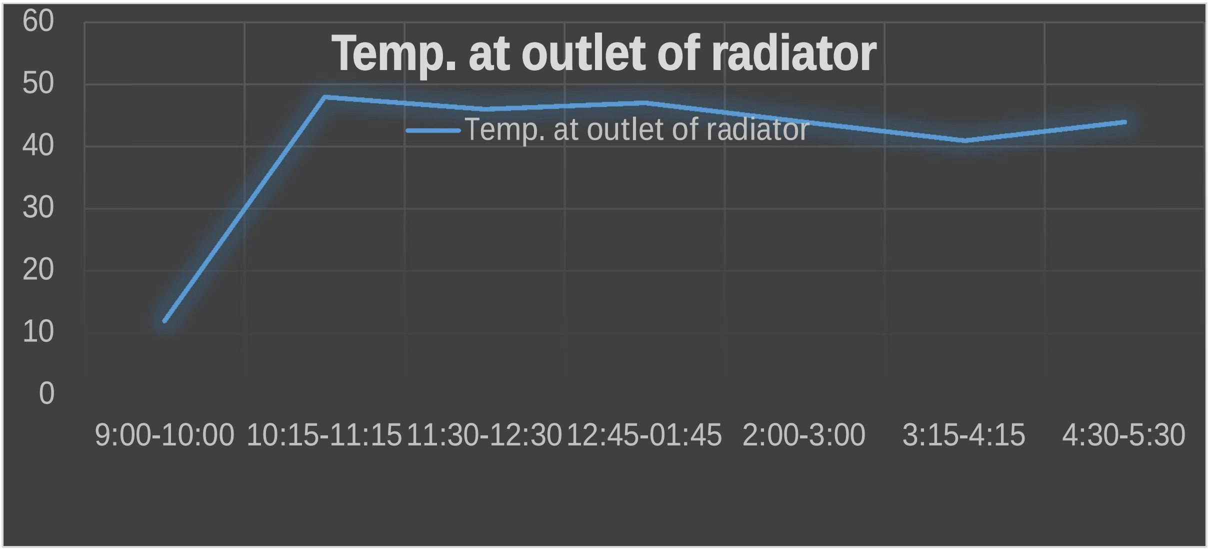
The exceptional heat dissipation characteristics, high surface area, and high thermal conductivity of Al2O3 nanoparticles are utilised in this application. By helping to keep the engine temperature within an ideal range, the coolant's distributed nanoparticles can enhance heat absorption and dissipation and prolong the engine's lifespan.

It's crucial to remember that adding nanoparticles to the coolant system necessitates extensive testing and analysis to guarantee their safety, compatibility with the coolant, and general efficacy in improving heat transmission. Furthermore, in order to get the intended thermal improvement without negatively affecting the engine or other cooling system components, appropriate dispersion techniques and monitoring systems must be in place.

Table 2 Using Al_2O_3 +Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 26 March 2023)

Time	Concentration (%)	Coolant in temp.	Temp. at outlet of radiator	Ambient temp.	Heat transfer coefficient h (W/m2 K)	Viscosity (kg/m s)	Velocity (m/s)	Pressure loss (Pa)
9:00-10:00 AM	1	25	12	35	910	0.000878	0.36360	280.21
10:15-11:15 AM	2	305	50	38.6	910	0.000992	0.24732	240.534
11:30-12.:30 PM	3	318	48	40.3	910	0.001080	0.21107	219.37
12:45-01:45 PM	4	312	44	43.7	910	0.001490	0.18771	225.30
02:00-03:00 PM	5	319	42	45.4	910	0.002120	0.16500	247.11
03:15-04:15 PM	6	314	39	48.4	910	0.002640	0.11700	260.00
04:30-05:30 PM	7	321	36	41.6	910	0.0034500	0.08850	242.92





Graph 1 Using Al2O3 +Paraffin wax Nanoparticles with Coolant in Car Coolant Tank.

2) Case 2: Using CuO+Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 27 March 2023)

As of March 27, 2023, adding CuO nanoparticles to the coolant in an automobile coolant tank is a novel way to improve the coolant's thermal conductivity and cooling effectiveness. It is anticipated that the dispersion of CuO nanoparticles in the coolant will greatly enhance its heat transfer characteristics, hence optimising the engine's overall cooling performance.

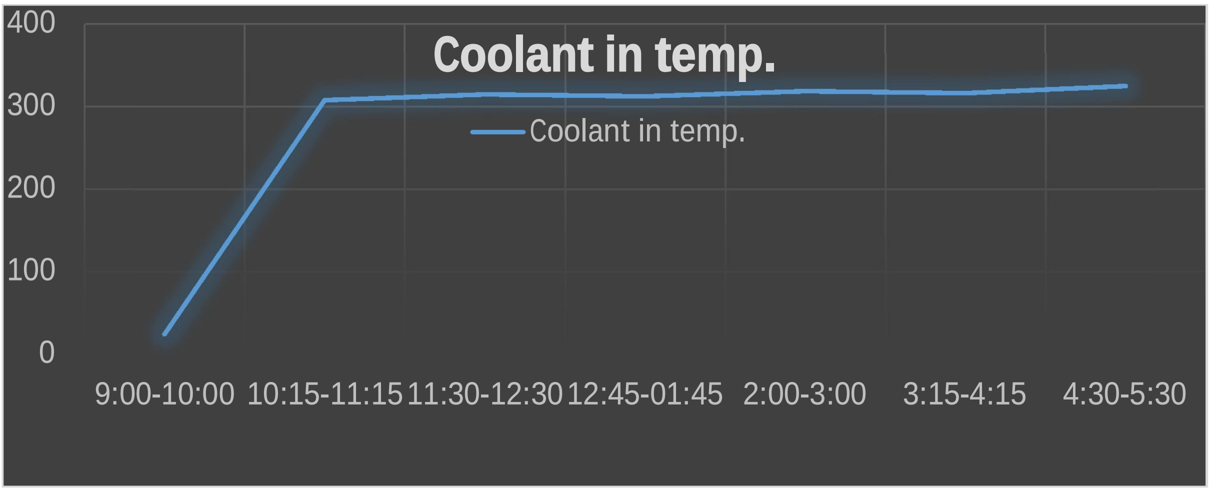
Al2O3 nanoparticles, which have a maximum temperature of 48.4°C and a minimum temperature of 36°C, can enhance heat absorption and dissipation in automotive coolant. As an alternative, the maximum temperature of CuO nanoparticles is 327°C, while the lowest temperature is 38°C. Compared to standard coolant, both solutions improve cooling; nevertheless, because of particle settling and possible compatibility problems, frequent system monitoring and maintenance are essential.

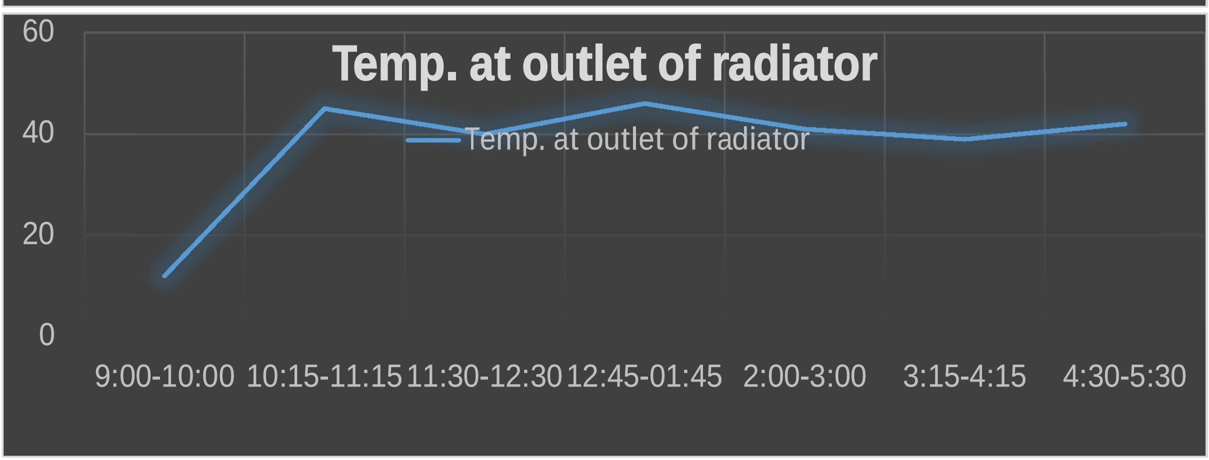
The exceptional heat dissipation characteristics, high surface area, and high thermal conductivity of CuO nanoparticles are utilised in this application. By helping to keep the engine temperature within an ideal range, the coolant's distributed nanoparticles can enhance heat absorption and dissipation and prolong the engine's lifespan.

Table 3 Using CuO+Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 27 March 2023)

Time	Concentration (%)	Coolant in temp.	Temp. at outlet of radiator	Ambient temp.	Heat transfer coefficient h (W/m2 K)	Viscosity (kg/m s)	Velocity (m/s)	Pressure loss (Pa)
9:00-10:00 AM	1	25	12	38.4	910	0.000896	0.4074	346.50
10:15-11:15 AM	2	310	42	40.2	910	0.001180	0.2229	232.62
11:30-12.:30 PM	3	318	43	43.2	910	0.001330	0.2977	249.70
12:45-01:45	4	320	49	47.8	910	0.001970	0.2141	242.92

PM								
02:00-03:00 PM	5	323	44	49.1	910	0.002494	0.1870	237.30
03:15-04:15 PM	6	319	38	50.6	910	0.003008	0.1420	241.11
04:30-05:30 PM	7	327	42.5	48.2	910	0.003879	0.0616	223.09





Graph 2 Using CuO+Paraffin wax Nanoparticles with Coolant in Car Coolant Tank.

3) Case 3: Using CuO+Al2O3+Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 28 March 2023)

As of March 28, 2023, adding CuO+Al2O3 mixing nanoparticles to the coolant in an automobile coolant tank is a novel way to improve the coolant's thermal conductivity and cooling effectiveness. It is anticipated that the dispersion of particles from the CuO+Al2O3 combination will greatly enhance the coolant's heat transfer characteristics, hence optimising the engine's overall cooling performance.

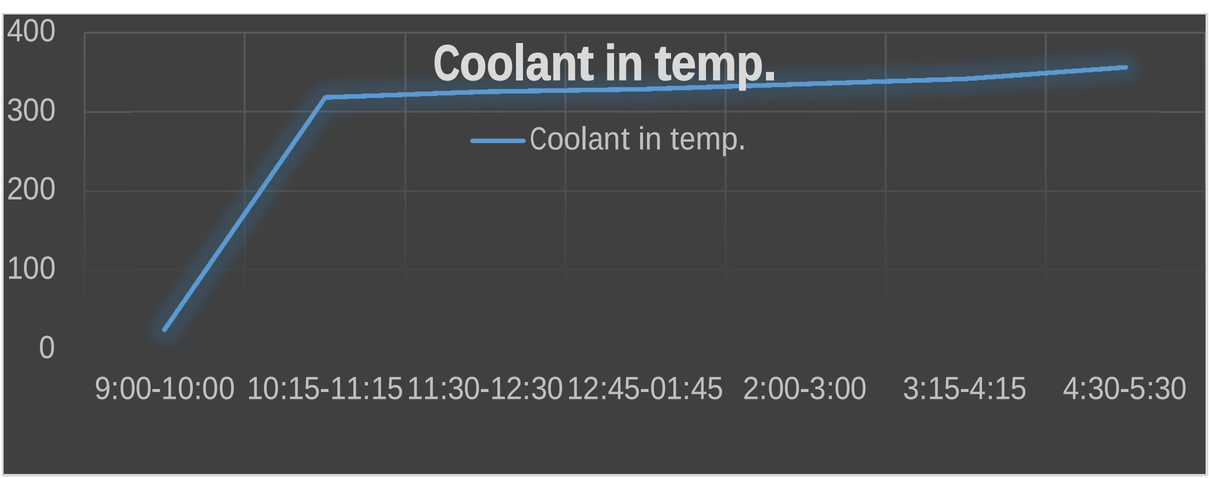
When compared to regular coolant, the automobile coolant's ability to absorb heat and dissipate heat is greatly enhanced by the use of Al2O3 nanoparticles. When the coolant exits the engine with Al2O3, it may reach a maximum temperature of 321°C and a low temperature of 36°C after going through the radiator. In contrast, a minimum temperature of 38°C and a maximum temperature of 327°C are reached when CuO nanoparticles are employed.

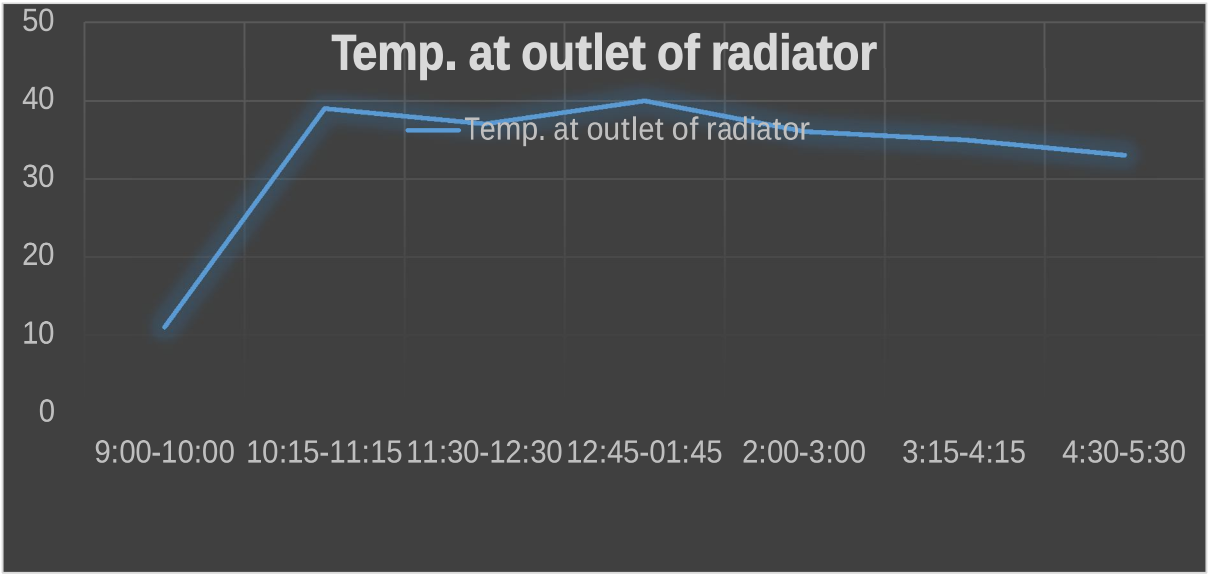
Nevertheless, the synergistic impact of the combined Al2O3 and CuO nanoparticles in the coolant yields even more impressive performance. The two-nanoparticle coolant reaches 367°C at its highest point when it leaves the engine and stays at a minimum of 32.7°C after it cools in the radiator.

The strong thermal conductivity, large surface area, and superior heat dissipation characteristics of CuO+Al2O3+Paraffin wax combination nanoparticles are utilised in this application. By helping to keep the engine temperature within an ideal range, the coolant's distributed nanoparticles can enhance heat absorption and dissipation and prolong the engine's lifespan.

Table 3 Using CuO+Al2O3 +Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 28 March 2023)

Time	Concentration (%)	Coolant in temp.	Temp. at outlet of radiator	Ambient temp.	Heat transfer coefficient h (W/m2 K)	Viscosity (kg/m s)	Velocity (m/s)	Pressure loss (Pa)
9:00-10:00 AM	1	25	13	35	915	0.0009948	0.27401	332.88
10:15-11:15 AM	2	322	42	38.8	925	0.001182	0.11700	179.11
11:30-12.:30 PM	3	329	39.4	36.6	928	0.001695	0.2040	220.56
12:45-01:45 PM	4	338	41.6	37.7	930	0.001929	0.17128	227.73
02:00-03:00 PM	5	355	39.3	42.5	933	0.002673	0.14580	215.12
03:15-04:15 PM	6	360	37.1	45.1	939	0.003264	0.11216	201.40
04:30-05:30 PM	7	367	32.7	40.3	948	0.00390	0.06061	168.80





Graph 3 Mixed Particles CuO+Al2O3+Paraffin wax Nanoparticles with Coolant in Car Coolant Tank. (on Date 28 March 2023)

This graph shows how, while keeping a fixed coolant mass flow rate, cooling capacity and efficacy fluctuate when air flow rate varies at different rpm. The y-axis displays the effectiveness, while the x-axis displays the air flow rate. At 42.7°C, the incoming ambient temperature has been maintained consistently. The plotted graphs show that while cooling capacity rises by 15% when pressure loss drops by 215.75% while keeping constant coolant mass flow rates, effectiveness does not vary when air flow rate increases.This strategy should be further improved and optimised by technology, opening up even more possibilities for automotive applications.

III. CONCLUSION

To sum up, employing nanofluids—that is, fluids that include nanoparticles of paraffin wax or oxides of aluminium and copper—in a car's cooling system offers a notable improvement over traditional coolants in terms of heat absorption and dissipation. The engine cooling system's overall thermal performance is enhanced by these nanoparticles, albeit the precise nanoparticle utilised may cause some temperature range differences.

1) Al_2O_3 +Paraffin wax Nanoparticles:

• 321°C is the maximum temperature that exits the engine.

• 36°C is the lowest temperature after the radiator cools.

• Al2O3+Paraffin wax nanoparticles show remarkable stability and efficiency in heat transmission. They improve heat removal and successfully boost the coolant's boiling point. Particularly in colder climes, the minimum temperature of 36°C after passing through the radiator guarantees protection against freezing.

2) CuO +Paraffin wax Nanoparticles:

• 327°C is the maximum temperature that exits the engine.

• 38°C is the lowest temperature after the radiator cools.

• CuO+ Paraffin wax nanoparticles effectively raise the coolant's boiling point and improve heat transmission. They do, however, need to be well maintained and could be more prone to settling.

3) CuO+Al_2O_3 + Paraffin wax Nanoparticles:

• 367°C is the maximum temperature that exits the engine.

• 42.7°C is the lowest temperature after the radiator cools.

• CuO and Al2O3+ Paraffin wax nanoparticles work together to improve the coolant's capacity to absorb and dissipate heat. It is the best option for effectively controlling engine temperature as it reaches the greatest maximum temperature as it exits the engine and keeps the lowest minimum temperature after radiator cooling.

Ultimately, the combination of CuO+Al2O3+ Paraffin wax nanoparticles is the best option because it offers exceptional low-temperature protection, a high maximum temperature capacity, and outstanding heat transfer efficiency. The benefits of engine temperature management outweigh the minor compatibility and particle settling concerns, which makes it an appealing alternative for vehicle cooling systems. To completely enjoy these benefits, though, the coolant system must be properly maintained and monitored.

a) Case 1: Al2O3 +Paraffin wax Nanoparticles (March 26, 2023)

On March 26, 2023, Al2O3+Paraffin wax nanoparticles were added to the automobile coolant, greatly increasing the efficiency of heat transmission. An improved capacity to disperse heat from the engine was demonstrated by the greater heat transfer coefficient (h). The system's pressure loss increased somewhat as the concentration of nanoparticles increased, despite a steady drop in viscosity and an increase in velocity. This suggests that whereas Al2O3+Paraffin wax nanoparticles improved heat transmission, managing the resulting pressure loss needs careful thought.

b) Case 2: CuO+Paraffin wax Nanoparticles (March 27, 2023)

As can be seen by looking at the increase in the heat transfer coefficient (h), the addition of CuO+Paraffin wax nanoparticles to the automobile coolant on March 27, 2023, significantly improved heat transfer efficiency. The fluid flow was aided by the concurrent rise in velocity despite the small increase in viscosity. CuO+Paraffin wax nanoparticles were added, and the system responded well, indicating the possibility of better heat dissipation. For best results, though, viscosity, velocity, and pressure loss must be carefully balanced.

c) Case 3: CuO+Al2O3+Paraffin wax Nanoparticles (March 28, 2023)

On March 28, 2023, the automobile coolant containing paraffin wax nanoparticles and CuO together showed improved heat transfer capacities. Better heat dissipation was indicated by a greater heat transfer coefficient (h). Pressure loss in the system showed an overall increasing trend, despite a minor drop in viscosity and an increase in velocity. The combination of CuO with Al2O3 or paraffin wax nanoparticles elicited a favourable response from the system, suggesting the possibility of enhanced heat transmission. Optimising the trade-offs between improved thermal characteristics and pressure loss requires striking a careful balance between nanoparticle concentrations.

The fundamental component determining the balance between higher viscosity and better thermal conductivity has been identified as optimal nanoparticle concentration. Achieving the proper concentration is essential to avoid excessive viscosity, which might impair flow dynamics and pump performance. The heat transfer coefficient (h), a crucial measure of increased heat dissipation efficiency in the radiator system, significantly increased with the addition of nanoparticles.

Furthermore, it was clear that attaining the intended outcomes required careful consideration of operating circumstances and system compatibility. Important procedures included making sure the nanofluid was compatible with radiator materials and other components and evaluating its stability at different operating temperatures.

it seems like you're looking for recommendations or potential uses for a combination of CuO, Al2O3, and paraffin wax nanoparticles. Here are a few potential applications and suggestions based on the properties of these materials.

1) CuO and Al2O3 nanoparticles are known for their catalytic properties. Combining them with paraffin wax as a matrix could create a catalytic material for specific chemical reactions.
2) Paraffin wax is a phase-change material that can store and release thermal energy. Introducing CuO and Al2O3 nanoparticles into the paraffin wax matrix can enhance its thermal conductivity and efficiency as a heat storage material.
3) Copper oxide (CuO) nanoparticles have antimicrobial properties. Incorporating them with aluminum oxide nanoparticles and paraffin wax could lead to the development of antimicrobial coatings for various surfaces.
4) Paraffin wax nanoparticles can be used for controlled drug delivery. Adding CuO and Al2O3 nanoparticles to the formulation may provide additional functionalities, such as targeted delivery or imaging capabilities.
5) Create composite materials with improved mechanical and thermal properties by dispersing CuO and Al2O3 nanoparticles in a paraffin wax matrix. This can be useful in industries such as aerospace or automotive for lightweight, high-performance materials.
6) Both CuO and Al2O3 nanoparticles have sensing properties. Incorporating them into a paraffin wax matrix could lead to the development of sensors for specific gases or environmental conditions.

7) Explore the use of CuO and Al2O3 nanoparticles in conjunction with paraffin wax for applications in batteries, supercapacitors, or other electrochemical devices.

To sum up, the thoughtful use of nanofluids into car radiator systems has the potential to completely transform automotive cooling systems. The enhanced heat transfer efficiency that follows leads directly to improved engine performance, fuel efficiency, and overall vehicle durability. This strategy should be further improved and optimised by future studies and developments in nanofluid technology, opening up even more possibilities for automotive applications.

IV. FUTURE SCOPE

The innovative approach of enhancing automotive radiator performance through nanofluid-based heat transfer, coupled with the incorporation of phase change materials (CuO or Al2O3 and paraffin wax), sets the stage for multifaceted future research. Further optimization studies, exploring a spectrum of nanoparticle concentrations and varied phase change material compositions, will fine-tune the system for diverse automotive applications. Long-term durability assessments will be pivotal to address potential wear, corrosion, and material stability concerns in real-world conditions. Integrating the proposed system with advanced cooling technologies, assessing its environmental impact, and adapting it for electric vehicles constitute crucial avenues for exploration. Collaborative partnerships with automotive manufacturers, coupled with economic feasibility studies, will ensure the seamless integration of this technology into commercial automotive production. Continuous research into innovative nanomaterials may uncover even more efficient alternatives. The future scope of this research extends beyond immediate improvements, aiming to position the proposed system as an economically viable, environmentally sustainable solution, contributing to the evolution of automotive thermal management and the broader landscape of sustainable transportation technologies.

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