EXPERIMENTAL STUDY FOR THERMAL PERFORMANCE AND PRESSURE LOSS CHARACTERISTICS ON A CAR RADIATOR USING NATURE (RICE HUSK) BASED SiO$_2$ NANO-FLUID

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Abstract

This study explores the potential of silicon dioxide (SiO$_2$) nanoparticles synthesized from rice husk to enhance the thermal performance of automotive radiators. By incorporating naturally derived SiO$_2$ nanoparticles into water, the research develops eco-friendly nanofluids aimed at improving heat dissipation in vehicle cooling systems. Experimental evaluations were conducted using a custom-built radiator test rig designed to replicate real-world operating conditions. Two nanoparticle volume concentrations—0.07% and 0.1%—were prepared and tested at varying flow rates of 2, 4, 6, and 8 liters per minute, with a consistent radiator inlet temperature of 55°C. The nanofluids demonstrated significantly improved thermal performance compared to the base fluid. Specifically, convection heat transfer rates increased by 20.77% and 38.07% for 0.07% and 0.1% SiO$_2$/water nanofluids, respectively. This enhancement is attributed to the improved thermal conductivity and energy transport properties imparted by the nanoparticles. However, the study also notes a rise in pressure drop at higher concentrations, which may increase the pumping power requirements of the system. Despite this, the results underscore the potential of using rice husk-derived SiO$_2$ nanofluids as a sustainable and efficient alternative to conventional coolants. The use of agricultural waste not only supports resource recycling but also reduces environmental impact associated with the production and disposal of synthetic coolants. Overall, this research provides a promising pathway for developing greener automotive cooling systems that contribute to better energy efficiency and environmental stewardship.

Keywords: Rice husk, Nano-particles, Nanofluid, Thermal performance, base fluid, Nano-silica.

1. INTRODUCTION

Heat exchangers are vital components in many engineering fields, including chemical processing, power generation, food production, environmental management, waste heat recovery, air conditioning, and refrigeration. Generally speaking, efforts to increase the rate of heat transmission are seriously limited by the low thermal conductivity of heat transfer fluids. With regard to the demands of modern technology for miniaturization, there is a need to develop new heat transfer fluids. Among the various heat transfer fluids, nanofluids have been proved to enhance thermal conductivity and performance. In 1995, Stephen U.S. Choi came up with the idea (Huminic & Huminic, 2012). A nanofluid is a mixture that consists of fluids and nanoparticles measuring just a few nanometers in size, typically ranging from 1 to 100 nm. These nanofluids are created by dispersing solid particles at the nanoscale into base fluids like ethylene glycol, water, and motor oil. The application of nanotechnology in heat transfer devices has significantly improved thermal performance across various sectors, including transportation, energy

production and distribution, heating and cooling systems, as well as electronics and microelectronics, along with other applications that operate on a micro scale (Abdelkareem, et al., 2022). Chowdhury & Salam increased heat transfer efficiency in flat plat solar collector using Al$_2$O$_3$ nanofluid (Chowdhury & Salam, 2017). Chowdhury et al., (2025) numerically investigated the heat transfer performance of Al$_2$O$_3$ nanofluids in smooth circular pipes with rectangular ribs of varying aspect ratios, demonstrating significant thermal enhancement. (Bahrami, Akbari et al., 2016) enhanced heat transfer by about 45% by creating a nanofluid—mixing nanoparticles into a water-antifreeze solution. This improvement highlights the promising potential of nanofluids in boosting the efficiency of thermal management systems like radiators. Chandrasekhar et al., (2003) found that Rice husk, widely used as fuel in rice mills, can cause environmental pollution when partially burned. To tackle this, controlled burning methods are being developed to convert its silica content (about 20%) into highly reactive amorphous silica. This fine material, with a large surface area, holds great potential for use in

various industrial applications. Osman & Sharifpur, (2019) created Al_2O_3 nanofluids by dispersing aluminum oxide nanoparticles in water, both with and without the addition of a surfactant. Their one-step process demonstrated that these nanofluids could enhance the heat transfer coefficient significantly—by as much as 54% in the transition flow regime and 11% in the turbulent flow regime at a concentration of 1 vol%. Zubair and Seraj et al., (2021) developed a nanofluid using titanium dioxide (TiO_2) mixed with water and ethylene glycol (EG) to serve as a coolant for radiators. The results showed that the volume flow rate, heat transfer, and convective heat transfer of this nano-coolant flowing through the radiator tubes were all enhanced. Asadi et al., (2019) carried out a comprehensive investigation into how ultrasonication parameters impact the stability and thermophysical characteristics of nanofluids. Their findings indicated that factors such as the power and duration of sonication play a crucial role in determining the stability, flow behavior, and thermal properties of these nanofluids. Hemmat Esfe et al. (2015) investigated the impact of nanoparticle volume fraction on the thermal conductivity and viscosity of a hybrid nanofluid containing silver (Ag) and magnesium oxide (MgO) in water. Using specific particle sizes and a 50:50 volume ratio, they developed new correlations that proved more accurate than existing models when compared to experimental data. Peyghambarzadeh et al., (2011) explored the use of water and ethylene glycol-based nanofluids as advanced coolants in a louvered fin, flat-tube car radiator. Their findings showed a 40% improvement in heat transfer compared to traditional base fluids. This enhancement was influenced by nanofluid concentration, flow conditions, and inlet temperature, indicating the strong potential of nanofluids for automotive thermal management. Ahmed et al., (2018) enhanced car radiator performance by using a TiO_2-water nanofluid instead of pure water. Testing concentrations of 0.1%, 0.2%, and 0.3% at different flow rates, they found that a 0.2% concentration significantly improved cooling efficiency—achieving a 47% boost. This demonstrates the strong potential of TiO_2 nanofluids for more efficient automotive cooling systems. Tafakhori et al., (2020) studied iron oxide-water nanofluids for car cooling and found that while higher nanoparticle concentrations increased density and viscosity, the best heat transfer improvement occurred at just 0.1% concentration. For optimal performance, they recommend 0.1% nanoparticle concentration, 2000 rpm fan speed, and 80–88°C inlet fluid temperature. (Muhammad Qasim et al., 2020) conducted an experimental study on Suzuki Mehran's radiator showed that water-based nanofluids with 0.2% ZnO nanoparticles improved heat transfer by up to 41%, overall heat transfer coefficient by 50%, and Nusselt number by 31%. However, higher

concentrations increased pressure drop and friction, highlighting the need to balance nanoparticle levels for optimal cooling performance. Elibol et al. (2022) studied on heavy vehicle radiators using TiO_2-water nanofluids found optimal heat transfer at 0.05% concentration, 80°C inlet temperature, and 11 LPM flow rate. Performance remained efficient between 0.025% and 0.05% concentrations, while higher concentrations increased pressure drop. Ong et al., (2022) investigated the use of nano-silica derived from rice husk as a heat transfer medium. To create the SiO_2 nano-coolant, various concentrations of SiO_2 nanoparticles were dispersed in a mixture of ethylene glycol and water using ultrasound. Scanning Electron Microscopy (SEM) was employed to analyze the surface morphology and particle size. The experiments were conducted on a car radiator to assess the thermal profile and longevity of the nano-coolant. The results indicated that the nano-silica particles had an irregular shape, and as the concentration of SiO_2 increased, so did the heat transfer performance. Specifically, the average heat transfer coefficient improved with higher nanofluid volume concentrations, leading to enhanced radiator efficiency.
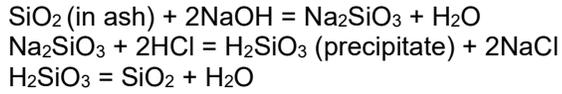
This study uses water as the base fluid with nanoparticle concentrations different from the previous research. It also examines pressure drop characteristics and nanoparticle preparation methods that vary from earlier study as I illustrated before. Various nanofluid concentrations are compared with pure water to evaluate performance. Using natural SiO_2 nanofluids derived from rice husk as a coolant for car radiators offers a sustainable, cost-effective, and readily available solution. By repurposing agricultural waste, this approach enhances vehicle cooling efficiency while promoting environmental sustainability.

2. MATERIALS AND METHODOLOGY

2.1 Nano-silica Preparation

Raw rice husk (RH) was first prepared by drying it at 110 ºC for three hours and grinding it into fine particles with a size of about 0.4 mm. The processed RH was then stored at the same temperature for later use. To produce amorphous silica, 3 grams of the pretreated RH were heated in an air-flowing tube furnace at temperatures between 700 and 900 ºC for 1 to 2 hours, resulting in rice husk ash (RHA). The RHA was then combined with 100 mL of NaOH solution and boiled while being continuously stirred for three hours to dissolve the silica and other oxides. After filtering out the remaining solid material, the liquid filtrate was cooled in an ice bath to reach 0 ºC. At this stage, a 1M HCl solution was added until the pH dropped to 4, causing a white amorphous silica precipitate to form. This precipitate was collected using a vacuum filter,

thoroughly washed with deionized water, and dried at 110 ºC for three hours. The final product, silica powder, was carefully weighed and stored for further analysis. This process resulted in nano-silica with the desired grain size and ultra-low density SiO_2 is made by following equations (Ngoc et al., 2018).

SiO_2 (in ash) + 2NaOH = Na_2SiO_3 + H_2O
Na_2SiO_3 + 2HCl = H_2SiO_3 (precipitate) + 2NaCl
H_2SiO_3 = SiO_2 + H_2O
The full precipitation method below in a flowchart
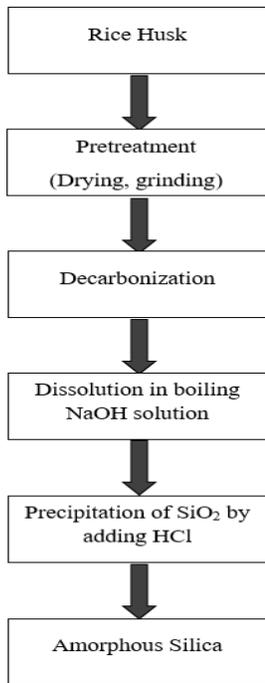
Fig. 1. Precipitate method in a flowchart for preparing rice husk to amorphous silica

(b)

(c)

(a)

(d)

(e)

(f)

(g)

Fig. 2. Nano-silica Preparation a) Rice husk b) Nano-sllica in weight scale c) Ball milling Machine d) Furnace e) Magnetic stiring of NaOH silica f) Mortar & pestle g) Adding HCl in the cold NaOH and silica mixture until the PH of the mixture neutral and precipitate SiO_2 Nano-fluid.

2.2 Characterization of Nano-silica

The ultra-low-density nano-silica produced was characterized using Scanning Electron Microscopy (SEM) at an accelerating voltage of 5 kV. This analysis allowed for a detailed examination of the surface morphology of the nano-silica particles, providing insights into their structure and characteristics.

2.3 Preparation of Nanofluid

In this study, nanofluids were created using SiO_2 nanoparticles extracted from rice husk ash (RHA) and mixed with water as the base fluid. The properties of water were noted, including a density of 983 kg/m³, specific heat capacity of 4200 J/kg, thermal conductivity of 0.61 W/m·K, and viscosity of 1.002×10^{-3} Ns/m², as reported by previous researchers. Nanofluid samples were prepared with volumetric concentrations ranging from 0% to 1%. The surface morphology and microstructure of the SiO_2 nanoparticles were analyzed using Scanning Electron Microscopy (SEM). The required number of nanoparticles can be determined by the volumetric concentration percentage in the equation and also based on previous research conducted by (Arani & Amani, 2012).

$$\frac{\frac{W_{particle}}{\rho_{particle}}}{\frac{W_{particle}}{\rho_{particle}}+\frac{W_{Fluid}}{\rho_{Fluid}}}\times100 \tag{1}$$

The production process involves using an ultrasonic mixer to blend the components for 8 hours, ensuring that the nanofluid becomes homogeneous. Nanofluids are created by dispersing nanoparticles within a base fluid, and their thermal-physical properties can be assessed using a governing equation for solid-liquid mixtures.

Fig. 3. Nanofluid preparation

2.4 Materials

Equations were collected from (Pak & Cho, 1998). Thermal conductivity of Nanofluid:

The model will be used to calculate the thermal conductivity of Nanofluid k_{nf} in this study

$$k_{nf} = \frac{k_p + (n-1)k_{bf} - \varphi(n-1)(k_{bf} - k_p)}{k_p + (n-1)k_{bf} + \varphi(n-1)(k_{bf} - k_p)} \qquad (2)$$

$$k_{nf} = \frac{k_p + (n-1)k_{bf} - \varphi(n-1)(k_{bf} - k_p)}{k_p + (n-1)k_{bf} + \varphi(n-1)(k_{bf} - k_p)} \qquad (3)$$

Dynamic viscosity
$$u_{n_f} = \mu_{bf}(1 + 2.5\,\varphi) \qquad (4)$$

Specific heat
$$c_{Pnf} = (1-\varphi)\left(\frac{\rho_{bf}}{\rho_{nf}}\right)c_{\dot{P}bf} + \varphi\left(\frac{\rho_{np}}{\rho_{nf}}\right)c_{\dot{P}np} \qquad (5)$$

Density of Nanofluid
$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_{bf} \qquad (6)$$

Table 1: Thermophysical properties of nanofluid used in the experiment

Properties	Base fluid	Base fluid + 0.1% SiO$_2$	Base fluid + 0.07% SiO$_2$
Density (kg/m³)	983.0	1149.5	1099.55
Specific heat (J/kg·K)	4200.0	3389.129	3606.605
Dynamic viscosity (Ns/m²)	1.002 × 10⁻³	1.2525 × 10⁻³	1.177 × 10⁻³
Thermal conductivity (W/m·K)	0.6100	0.6806	0.6586

Table 2: Mismeasured parameters of radiator

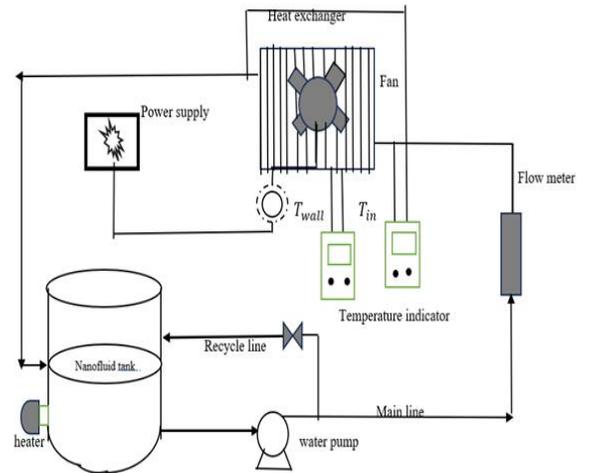| Parameters	Values
Radiator length	0.7 m
Radiator height	0.42 m
Radiator width	0.015 m
Tube length	0.65 m
Tube height	0.004 m
Tube width	0.018 m
Tube thickness	0.0001 m
Number of tubes	70

Fig. 4. Car Radiator

2.5 Block Diagram
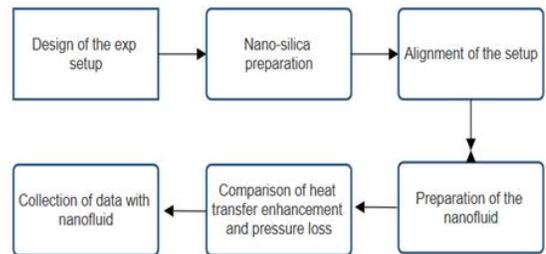
Fig. 5. The flow chart of the experiment

2.6 Nanofluid in radiator

Fig. 6. A schematic diagram of the experimental setup used in this work

Fig. 7. Front view of the experimental setup

Fig. 8. Rear view of the experimental setup

2.7 Mathematical Equation

From the cooling law (newton's cooling law), Heat transfer rate is given by,

$$Q_{nf} = h_{in} A_{in} \Delta T = h_{in} A_{in} (T_b)_{nf} - (T_w)_{nf} \quad (7)$$

where, A_{in} is the area of the inside surface area, h in is the coefficient of inside heat transfer, $(T_b)_{nf}$ is denoted as bulk fluid temperature which is the average of inlet temperature, $(T_{in})_{nf}$ and outlet temperature, $(T_{out})_{nf}$

$$(T_b)_{nf} = \frac{(T_{in})_{nf} + (T_{out})_{nf}}{2} \quad (8)$$

Again,

$$(T_w)_{nf} = \frac{T_1 + T_2 + \cdots + T_6}{6} \quad (9)$$

Where $(T_w)_{nf}$ is called the surface temperature of radiator wall (average). T_1 to T_6 is the temperature of different position of radiator wall.

The heat transfer coefficient of nanofluid will be calculated from,

$$Q_{nf} = \dot{m}_{nf} (C_p)_{nf} \Delta T = \dot{m}_{nf}(C_p)_{nf} \left((T_{in})_{nf} - (T_{out})_{nf}\right)$$

$$\quad (10)$$

where, $\dot{m}_{nf}$= mass flow rate of nanofluid.

And the heat transfer coefficient of air will be calculated from,

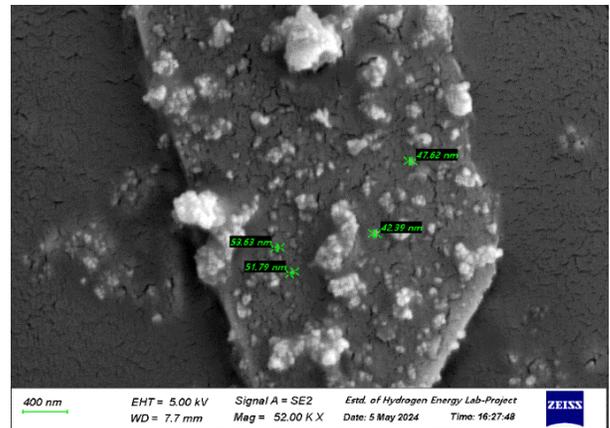$$Q_a = \dot{m}_{air} (C_p)_{nf} \Delta T = \dot{m}_{air}(C_p)_{air}\left((T_{in})_{air} - (T_{out})_{air}\right)$$

$$\quad (11)$$

where, $\dot{m}_{air}$=mass flow rate of air duct $(C_p)_{air}$ air is the specific heat capacity of air,

$(T_{in})_{air}$ and $((T_{out})_{air})$ is the inlet and outlet temperature of air.
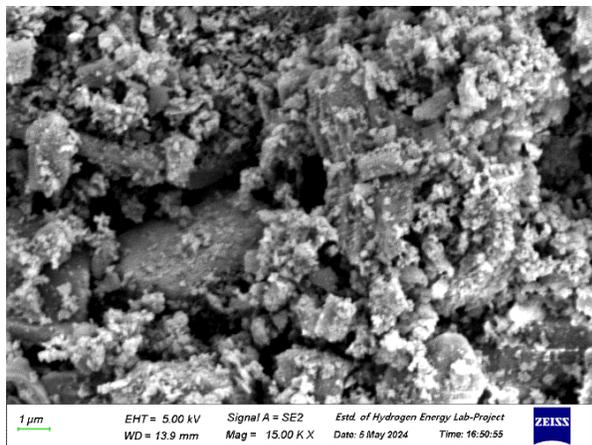
3.Results and discussions
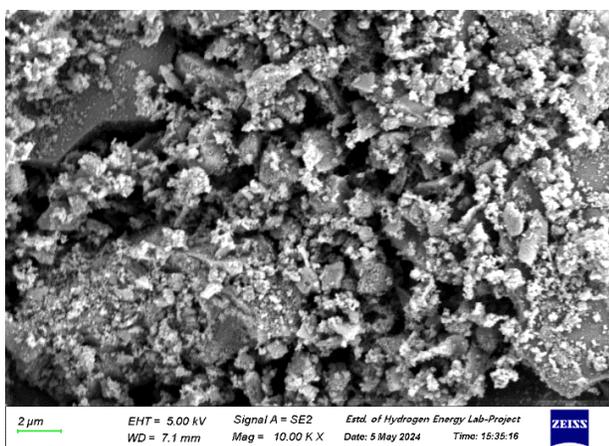
3.1 SEM Test Result

For evaluation of the Rice husk based SiO$_2$/Water nanofluid SEM (Scanning Electron Microscopy) was carried out. The finding is

(a)

(b)

(c)

Fig. 9. a) SEM image of Rice husk based SiO$_2$ nanoparticles under 52kx zoom b)15kx zoom c)10kx zoom

Nano-size confirmation: The sample contains nano-sized SiO$_2$ particles — confirmed by direct measurements in the SEM images (as small as ~17 nm).

Agglomeration: The particles tend to cluster together, making it difficult to find isolated, uniformly shaped particles. This is a common phenomenon in nanoparticles, especially SiO$_2$, due to their high surface area-to-volume ratio and surface energy and also synthesis or drying method, and suggesting that dispersion techniques could be applied for better particle separation.

No uniform morphology: The sample does not show a consistent or defined particle shape. The shapes are irregular and inconsistent.

Material quality note: While the presence of nanoparticles is confirmed, further processing such as

ultrasonication or surface modification might be necessary to reduce agglomeration.

3.2 Graphical Representation

We examined how different concentrations (0.07% and 0.1%) of rice husk-based SiO$_2$ nanofluid affect the heat transfer rate, pressure drop, heat transfer coefficient, and pumping power, comparing these results to those obtained with pure water. Our research highlighted the effectiveness of these concentrations in improving cooling efficiency, providing valuable insights for enhancing the energy efficiency and performance of automotive radiators. As shown in Figure 10, higher concentrations led to a notable increase in the heat transfer rate.
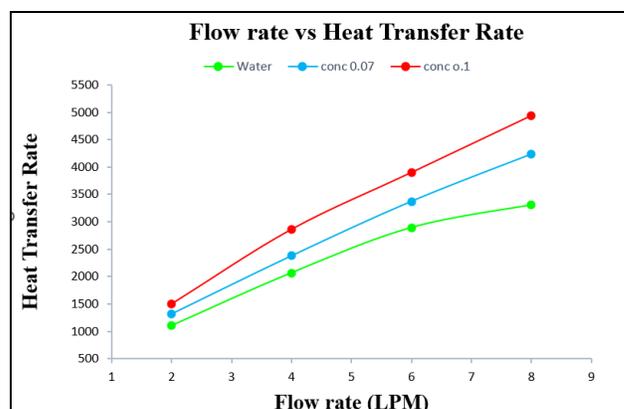
Fig. 10.: Variation of heat transfer rate with flow rate

In our experiment, we used two different concentrations of rice husk-based SiO$_2$/water nanofluid. We found that the heat transfer rate improved by 20.77% and 38.07%, depending on the concentration used. Figure 11 illustrates the percentage increase in heat transfer rate compared to water for the various concentrations tested.
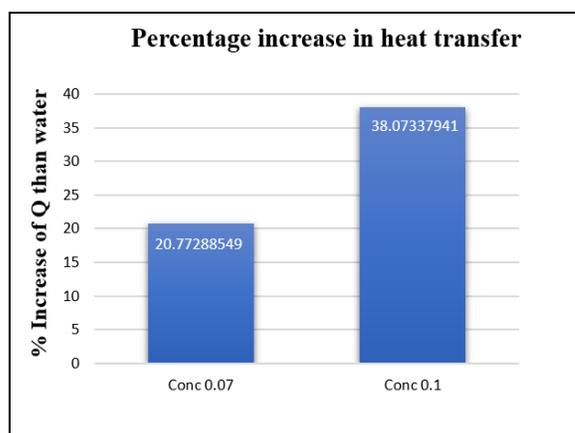
Fig. 11. Increased Heat Transfer with respect to Water in Percent

We calculated the heat transfer coefficients at various flow rates for two different concentrations of the nanofluid. The results of this analysis, when compared to those of water, are presented in Figure 12. This figure provides a clear visual representation of how the heat transfer coefficients vary with flow rates for both concentrations. By examining these results, we can better understand the performance enhancements offered by the nanofluid compared to conventional water, highlighting the effectiveness of different concentrations in improving thermal efficiency across a range of flow conditions.
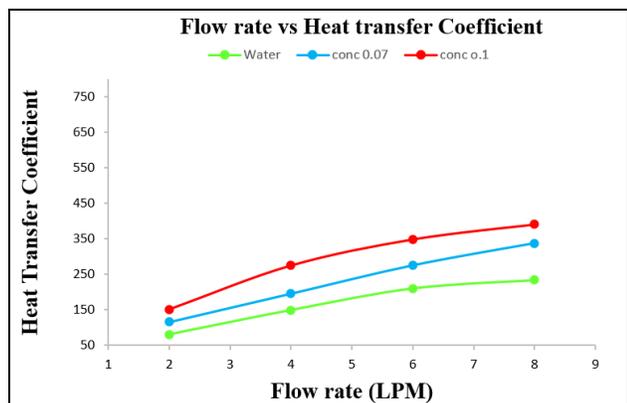

Fig. 12. Variation of heat transfer rate with flow rate

Figure 13 illustrates the percentage increase in the heat transfer coefficient of the nanofluid compared to water. The data clearly demonstrates a notable improvement in heat transfer performance as the concentration of the nanofluid increases. This indicates that higher concentrations of the nanofluid enhance its thermal properties, making it more effective at transferring heat than water alone. The findings highlight the potential benefits of using nanofluids in applications where efficient heat transfer is critical, as increasing their concentration can lead to significant performance gains.
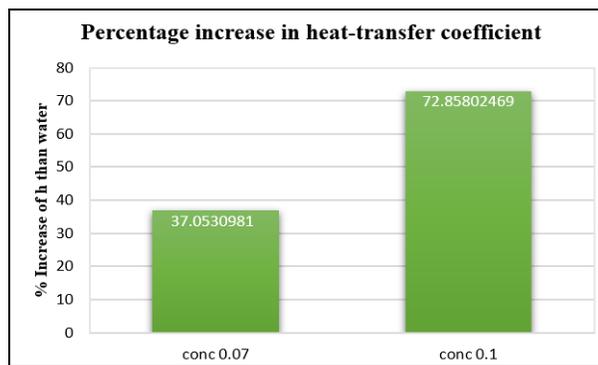

Fig. 13. Increased Heat Transfer coefficient with respect to Water in Percent

Figure 14 shows that rice husk-based SiO_2/water nanofluid with a 0.1% volume concentration transfers heat more efficiently than higher concentrations at the same pumping power. This means better thermal performance can be achieved without extra energy input, making it an energy-efficient option for heat transfer applications. The findings highlight the potential of these eco-friendly nanofluids to improve cooling and heat dissipation in various systems.
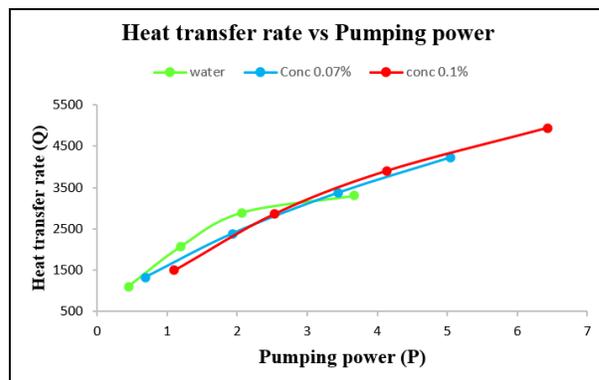

Fig. 14. Variation of Heat Transfer Rate with Pumping Power

When nanoparticles are dispersed in a base fluid to enhance its heat transfer capabilities, agglomeration—the tendency of particles to cluster together—can occur, particularly at higher concentrations. This aggregation negatively impacts the stability of the nanofluid, as it leads to sedimentation and inconsistent thermal performance. Initially, increasing nanoparticle concentration improves thermal conductivity and promotes enhanced energy transport through the fluid. However, this enhancement is not linear; beyond a certain concentration, the benefits begin to diminish due to increased viscosity, flow resistance, and particle agglomeration. In this study, the optimum concentration for maximum heat transfer was not determined, and nanofluid stability was not maintained or considered. These aspects may be addressed in future research to achieve more reliable and efficient thermal performance.

In this study, the addition of rice husk-based SiO_2 nanofluid resulted in a notable enhancement in heat transfer performance compared to water. Specifically, the 0.07% and 0.1% concentrations improved heat transfer rates by approximately 20.77% and 38.07%, respectively. However, Figure 14 reveals that although the 0.1% nanofluid offers a greater increase in heat transfer, it also leads to a significantly higher pumping power requirement due to increased pressure drop. In contrast, the 0.07% concentration achieves nearly comparable thermal performance with much lower additional pumping effort, indicating a better balance between efficiency and energy input. Therefore,

considering both heat transfer gain and the energy cost associated with increased pressure drop, 0.07% concentration appears to be the optimal choice, providing improved thermal performance without an abrupt rise in pumping power. Further studies could focus on identifying the exact pressure drop values and evaluating long-term operational stability for broader application use.

4.Conclusion

The rice husk-based SiO_2/water nanofluid shows significantly better thermal conductivity than regular water. When used as a coolant, it enhances the heat transfer coefficient, improving the cooling efficiency of car radiators. As the concentration of SiO_2 nanoparticles increases, the heat transfer performance also improves. Specifically, using 0.07% SiO_2 nanofluid leads to a 37.05% increase in the heat transfer coefficient, while 0.1% concentration boosts it by 72.85% compared to pure water. Similarly, the heat transfer rate also rises with increasing nanofluid concentration. The study found that 0.07% SiO_2 nanofluid increases heat transfer by 20.77%, whereas 0.1% concentration results in a 38.07% improvement. However, this improvement comes with a trade-off— higher pressure drops, especially at higher flow rates. The maximum pressure drop occurs at a flow rate of 8 LPM with 0.1% nanofluid, which indicates an increase in pumping power requirements.

One of the key advantages of using rice husk-based SiO_2 nanofluid is its sustainability. Derived from agricultural waste, it provides an eco-friendly alternative to conventional coolants, reducing environmental impact. This approach supports the use of renewable resources while minimizing reliance on synthetic coolants that may pose environmental hazards during production and disposal. This research contributes to the ongoing development of nanofluid technology, offering promising applications beyond automotive cooling. The improved heat transfer performance of SiO_2 nanofluids could benefit various industries, including power plants and electronic cooling systems. In the automotive sector, better cooling efficiency translates to improved engine performance, reduced maintenance costs, and longer engine lifespan, ultimately leading to economic benefits for vehicle owners.

To make rice husk-based SiO_2 nanofluids a practical and efficient solution for car radiators, a few key areas need further exploration. One important factor is improving the accuracy of temperature measurements. Using high-precision thermocouples and digital sensors will help ensure reliable data, leading to a better understanding of how these nanofluids perform in real-world conditions. Another challenge is keeping the nanoparticles evenly dispersed in the fluid. Over time, they tend to clump together and settle, reducing their effectiveness. Adding surfactant can help maintain stability, making the nanofluid more practical for long-term use. While water has been the main base fluid in this study, In this study, no surfactant was used or considered to prevent nanoparticle aggregation in the nanofluid. Sedimentation testing was also not conducted as part of the experimental procedure. Additionally, the ±% error or accuracy of the flowmeter used for measuring nanofluid or air flow rates was not determined, as it was beyond the primary scope of this research. However, these aspects may be considered in future research to enhance the accuracy and stability of the nanofluid system. alternatives like ethylene glycol or propylene glycol should be considered since they handle extreme temperatures better. It's also important to study how these nanofluids hold up over repeated heating and cooling cycles to determine their durability. Another key challenge is finding the right balance in nanoparticle concentration—while more nanoparticles improve heat transfer, they can also make the fluid thicker, increasing energy consumption. The selected concentrations of 0.07% and 0.1% were chosen because preliminary observations showed that the percentage increase in heat transfer was quite similar across nearby concentration levels. Therefore, one lower and one higher value were randomly selected to represent this range. In future research, a wider range of concentrations can be tested to determine the optimum concentration more precisely provides the best heat transfer benefits without significantly increasing the workload on the cooling system.

Apart from the technical improvements, it's also important to look at the broader impact. These findings highlight the broader potential of eco-friendly, agricultural waste-derived nanofluids in promoting energy efficiency and sustainability in thermal systems such as automotive radiators and industrial heat exchangers. For future research, it is recommended to address technical challenges such as long-term stability, agglomeration control, and optimization of concentration. Additionally, comprehensive economic and environmental impact assessments should be conducted to support large-scale industrial adoption of such green nanofluids.

Compliance with ethical standards

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