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ORIGINAL ARTICLE

Numerical Simulation of Heat transfer Enhancement in IC Engine using Al_2O_3-H_2O Nanofluids as a Coolant

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Abstract

Objectives: The focal objective of this article is to examine the influence of Al_2O_3-water based nanofluids as a coolant in IC engines. The nanoparticles are considered with different concentrations at various temperatures. **Methods:** Numerical simulations (MATLAB) were performed to explore the heat transfer characteristics of Al_2O_3-water nanofluids with varying nanoparticle concentrations (0.2%, 1%, 2%, 3%, 4%, and 5%) at various temperatures (50°C, 60°C, and 70°C). The mass flow rate of the nanofluid was varied, and the resulting heat transfer rates were evaluated. Thermal conductivity and viscosity were studied using 3D surface plots, and contour plots were used to observe the effects of temperature and volume fraction on thermal properties. **Findings:** The heat transfer rate increased with higher mass flow rates and nanoparticle concentrations. At higher Al_2O_3 concentrations, the enhancement ratio decreased, showing diminishing returns as the concentration increased from 0.2% to 5%. Thermal conductivity increased linearly with the volume fraction, while viscosity decreased with temperature and increased with higher particle concentrations. Nanofluids exhibited superior heat transfer performance compared to water, with higher concentrations of Al_2O_3 showing significant improvement. **Novelty** This study highlights the effectiveness of Al_2O_3-water nanofluids in enhancing heat transfer rates for IC engine applications. It provides a comprehensive understanding of how nanoparticle concentration and operating conditions influence thermal performance. The findings underscore the potential of nanofluids as a superior alternative to conventional cooling fluids for improving the thermal efficiency of IC engines.

Keywords: Nanofluids; Enhancement ratio; Contour plot; Coolant; Volume concentration

1 Introduction

The automotive radiator is an essential part of the cooling system, which impacts vehicle power and fuel efficiency, both of which are essential to the engine. The heat exchanger's development has been optimized using a variety of methods, including modifying the fins' design and adding more pipes. Since cooling efficiency and engine operating speed are related, car coolant cooling performance needs to be further enhanced. Enhancing the thermal conductivity of conventional coolants by altering their formulation is a potential approach given the current state of technology and environment. A radiator is a kind of heat exchanger found in almost every car on the market today. Water-ethylene fluid and water-propylene fluid are the two types of coolants that are now available. Propylene glycol (PG) coolants are more advantageous due to their low thermal conductivity when taking into account factors like boiling and freezing points, corrosion resistance, and most importantly, hazards to the environment. The radiator is simply one of the several components of the complex cooling system, displayed in the Figure 1.

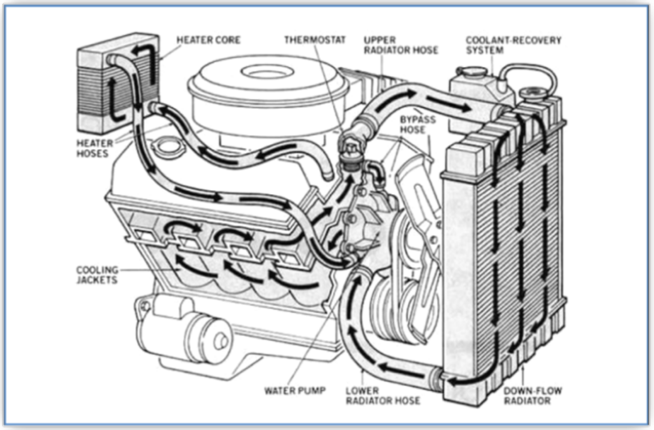

Fig 1. Cooling system of IC Engine

A homogenous mixture of liquids and solids with solid particles smaller than 100 nm is called a nanofluid. The purpose of adding these solid particles is to enhance the base fluid's thermophysical characteristics and heat transfer behavior. The use of nanofluids as coolant in automobile engines is a significant application. Choi introduced the idea of nanofluids in 1995, referring to fluids that contain particles known as nanoparticles (NPs), which are nanometer-sized particles. Early studies on nanofluid heat transfer began with the exploration of materials like Al_2O_3 and CuO nanoparticles suspended in water and other base fluids, revealing their potential for heat transfer enhancement[1],[2]. These advancements have been extended to automotive applications, such as improving radiator performance and cooling efficiency, with several researchers look over into the effects of different nanofluid compositions on heat transfer rates and system performance[3]-[4]. The ability of nanofluids to improve thermal conductivity has led to their widespread adoption in automotive radiators, with studies demonstrating enhanced cooling performance[5],[6].

Recent research has also explored the impact of nanoparticle size, shape, and concentration on the heat transfer capabilities of nanofluids, emphasizing the importance of these parameters in optimizing radiator function[7],[8]. Additionally, numerical simulations and experimental studies have investigated the performance of different nanofluid compositions in various engine components, such as the internal combustion engine and the diesel engine cylinder head[9]. Comparative performance analysis is performed by applying a mixer of Al_2O_3 and CuO-nanofluid and ethylene glycol as base fluid for internal combustion engine water jacket coolant[10]. Moreover, the integration of nanofluids into compact heat exchangers has shown potential in enhancing heat transfer rates and overall efficiency, thus contributing to improved engine cooling and thermal management[11]. Generally, Al_2O_3 nanofluids with diverse volumetric concentrations provide noteworthy increment in heat transfer coefficient. It also increases thermal conductivity thereby enhancing thermal properties[12]-[13]. Convective heat transfer performance is evaluated using numerical simulation for various nanofluids using water as hot fluid[14]-[15]. Hall current and Radiation effect with melting heat transfer in a hybrid nanofluid flows across a variable thickness sheet is considered and observed that the flow parameters significantly enhance the heat transfer[16]. In decision, the application of nanofluids in automotive cooling systems represents a significant step forward in the development of more efficient and sustainable thermal management solutions. As research continues to evolve, the integration of nanofluids into practical automotive applications will likely play a pivotal role in achieving higher vehicle performance, lower fuel consumption, and better overall thermal efficiency. Few research on the heat transfer performance of nanofluids in IC engines have been published to date; the majority has concentrated on the effects of temperature, velocity, and volume concentration. Al_2O_3/water nanoparticles of various forms were utilized to create nanofluids with particle sizes of 30, 30, and 10 nm, respectively, in order to examine the impact of particle type and size on the heat transfer capability of nanofluids. Additionally, a simulation study was carried out in this article. The impact of particle motion on heat transfer performance can be examined by comparing the simulation and experimental data. This fills a gap in the body of observed investigations.

2 Methodology

2.1 Preparation of Nanofluids

The Al_2O_3-water nanofluid utilized in the present investigation has variable properties; its viscosity and thermal conductivity vary in response to temperature and the volume fraction of nanoparticles. Making a suspension of nanoparticles is the first step in using nanofluid to improve heat transmission. The heat transfer rate was investigated in the present work using Al_2O_3 nanoparticles dispersed in water and having an average diameter of 11 nm. This is due to the fact that any agent added may alter the characteristics of the nanofluid. To investigate increased heat transfer, nanofluids containing six distinct concentrations of Al_2O_3 nanoparticles (0.2%, 1%, 2%, 3%, 4%, and 5% volume fraction) were made. The thermophysical characteristics of Al_2O_3/water nanoparticles are shown in Table 1.

Table 1. Thermophysical properties of Al_2O_3/water nanoparticles

Material	Density (ρ), (*kg/m*^{3})	Specific heat (C_P) (*J/kg K*)	Thermal conductivity (K) (*W/m K*)	Viscosity (μ) (*kg/m s*)
Al_2O_3	3970	40	765	-
Water	998.2	0.6	4182	0.001

The following equations apply to the volume fraction and density of the suspended nanoparticles:

$$\phi = \frac{v_s}{v_t} \tag{1}$$

and

$$\rho_s = \frac{m_s}{v_s} \tag{2}$$

Here, the mass of the nanoparticles for the suspension of nanofluids is determined as follows:

$$m_s = 1 \times 10^{-3} \times \nu \times \rho_s \tag{3}$$

2.2 Thermo physical properties of Nanofluids:

Based on the characteristics of water and nanoparticles, the thermophysical characteristics of the nanofluid, such as density, specific heat, thermal conductivity, and viscosity, were calculated.

Density of nanofluid:

$$\rho_{nf} = (\phi \times \rho_s) + ((1-\phi) \times \rho_w) \tag{4}$$

Where ρ_{nf} is the density of nanofluid,
ϕ is the volume concentration,
ρ_s is the nanoparticles density and
ρ_w is the density of basefluid.

Specific heat of nanofluid:

$$(C_P)_{nf} = \frac{\nu \times \rho_s \times (C_P)_s + (1-\phi) \times \rho_w \times (C_P)_w}{\rho_{nf}} \tag{5}$$

Where $(C_P)_{nf}$ is the specific heat of nanofluid,
$(C_P)_s$ is the specific heat of the nanoparticles and

$(C_P)_w$ is the specific heat of base fluid (water).

Thermal conductivity of nanofluid (Maxwell model):

$$K_{nf} = \left[\frac{K_s + 2K_w + 2(K_s - K_w)(1+\beta)^3\phi}{K_s + 2K_w + (K_s - K_w)(1+\beta)^3\phi}\right] \times K_w \tag{6}$$

where K_{nf} is the thermal conductivity of nanofluid,

K_s is the thermal conductivity of nanoparticles and

K_w is the thermal conductivity of base fluid

Dynamic viscosity of nanofluid:

$$\mu_{nf} = \mu_w(1 + 2.5\phi) \tag{7}$$

Where μ_{nf} is the viscosity of nanofluid and

μ_w is the viscosity of base fluid (water)

Effective nanofluid thermal conductivity was calculated using $\beta = 0.1$ and the ratio of nanolayer thickness to the original particle radius. Table 2 displays the thermophysical characteristics of Al_2O_3 and water nanoparticles for varying volumetric concentrations, which are computed using the aforementioned formulae.

Table 2. Thermo physical properties of Al_2O_3 nanoparticles with volume concentration

Material	**Density (ρ), (*kg/m³*)**	**Specific heat (C_P) (*J/kg K*)**	**Thermal conductivity (K) (*W/m K*)**	**Viscosity (μ) (*kg/m s*)**
$\phi = 0.2\%$	1004.1	4155	0.6046	0.0010
$\phi = 1\%$	1027.9	4050	0.6232	0.0010
$\phi = 2\%$	1057.6	3925.5	0.6470	0.0011
$\phi = 3\%$	1087.4	3807.7	0.6715	0.0011
$\phi = 4\%$	1117.1	3696.2	0.6966	0.0011
$\phi = 5\%$	1146.8	3590.5	0.7223	0.0011

The temperature and mass flow rates, the heat transfer rate at the water side and air side of the radiator can easily defined by the for the following equations.

$$Q_{nf} = m_{nf} \times (C_P)_{nf} \times \Delta T \tag{8}$$

Here, Q_{nf} is the heat transfer rate of nanofluid in kJ/s,

m_{nf} is the mass flow rate of nanofluid in kg/s,

$(C_P)_{nf}$ is the Specific heat of nanofluid in KJ/kg. K and

ΔT is the difference between the inlet and outlet nanofluid temperature in K.

Several systematic approaches will be used in the present investigation, and they will be implemented one after the other. Analyzing the convective heat transfer of Al_2O_3/water nanofluids for internal combustion engine cooling is the first stage. The next step is to choose or identify the solution method's boundary conditions. The program gets started in the third stage, and the process is then executed and simulated in the final step.

3 Results and Discussion

The numerical simulations were performed by varying the nanofluid flow rate at a given concentration. The varying mass flow rate (kg/s) of the nanofluid flowing with different concentration (Water, 0.2%, 1%, 2%, 3%, 4% and 5%) inside the radiator are considered with temperatures 50°C, 60°C and 70°C. The numerical simulation obtained in this study is confirmed with the outcomes furnished by Moo-YeonLee Hamid and Kunal Sandip Garud with same geometrical structures, dimension and boundary conditions.

Figure 2 illustrates the relationship between the heat transfer rate (in watts) and the mass flow rate (in kg/s) at a temperature of 50°C for water and Al_2O_3-water nanofluids with different concentrations of Al_2O_3 (ranging from 0.2% to 5%). As the mass flow rate increases, the heat transfer rate also increases across all fluids. Higher concentrations of Al_2O_3 in the nanofluid enhance the heat transfer rate, showing improved performance compared to water alone. This highlights the effectiveness of Al_2O_3 nanofluids in boosting effectiveness of heat transfer at various flow rates.

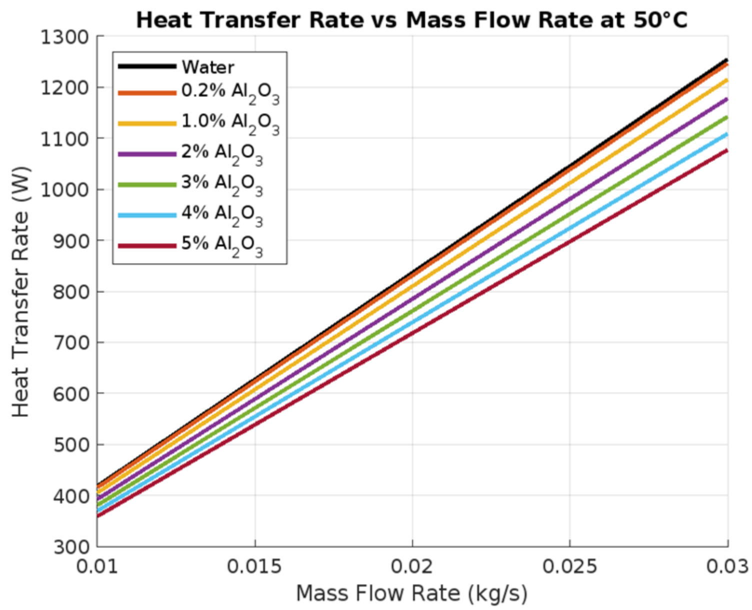

Fig 2. Heat Transfer Rate vs Mass flow rate at 50°

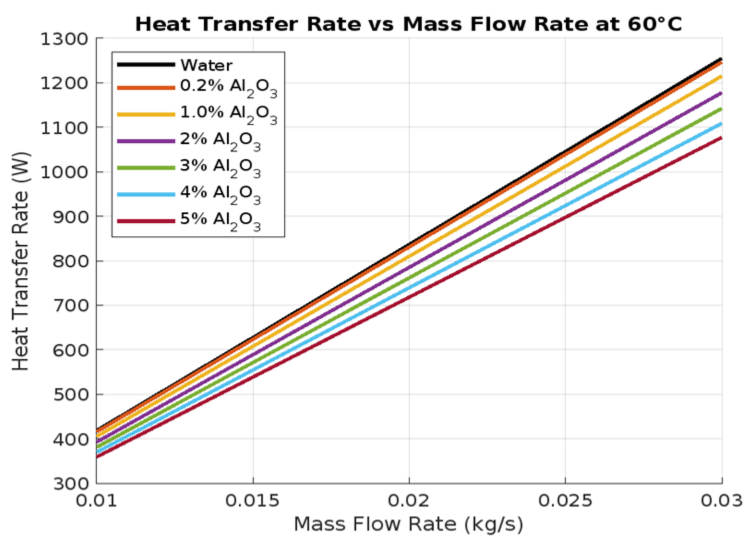

Fig 3. Heat Transfer Rate vs Mass flow rate at 60°C

Figure 3 shows the heat transfer rate (in watts) versus the mass flow rate (in kg/s) at a temperature of 60°C for water and various Al_2O_3-water nanofluid concentrations (from 0.2% to 5%). when mass flow rate upsurge, the heat transfer rate also rises for each fluid. Nanofluids with higher Al_2O_3 concentrations demonstrate enhanced heat transfer rates compared to water, indicating that Al_2O_3 nanofluids are effective in improving heat transfer at elevated temperatures and flow rates.

Figure 4 describes the relationship between heat transfer rate and mass flow rate at 70°C for pure water and nanofluids with varying concentrations of aluminum oxide (Al_2O_3). As mass flow rate increases, heat transfer rate rises linearly for all fluids. Nanofluids with Al_2O_3 outperform pure water in heat transfer, with higher concentrations (0.2% to 5%) providing greater enhancement. This suggests Al_2O_3 nanofluids could be more effective than water for heat transfer applications.

Table 3 shows that as Al_2O_3 concentration increases from 0.2% to 5%, the enhancement ratio decreases from 0.9935 to 0.8586, indicating diminishing returns with higher nanoparticle concentration.

Figure 5 depicts 3D surface plot for thermal conductivity $(\mathrm{W/m \cdot K})$ as a function of temperature (°C) and volume fraction of a substance. Thermal conductivity increases with both higher volume fractions and lower temperatures, as shown by the

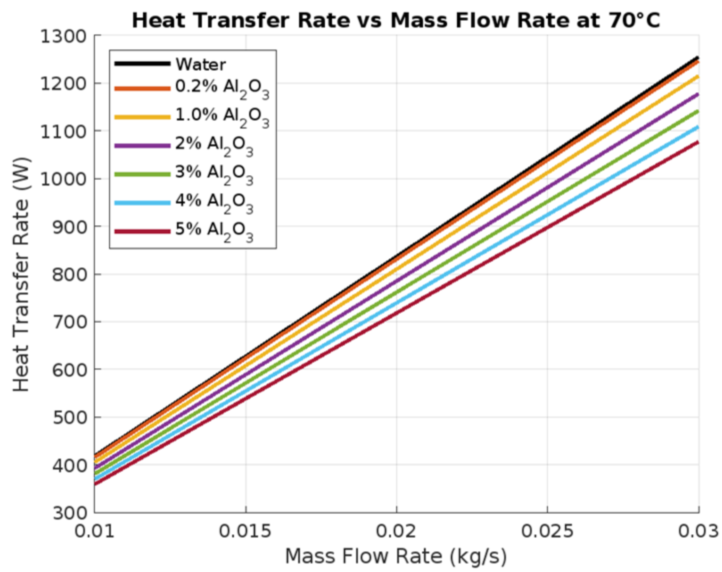

Fig 4. Heat Transfer Rate vs Mass flow rate at 70°C

Table 3. Heat transfer enhancement ratio

Concentration	Enhancement Ratio
0.2% of Al_2O_3	0.9935
1% of Al_2O_3	0.9684
2% of Al_2O_3	0.9387
3% of Al_2O_3	0.9105
4% of Al_2O_3	0.8838
5% of Al_2O_3	0.8586

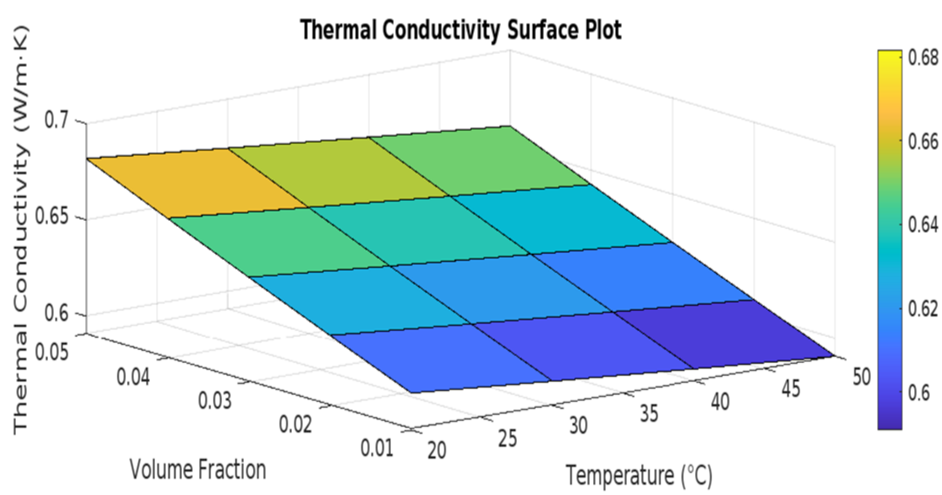

Fig 5. Thermal Conductivity with Volume fraction

gradient from blue (lower conductivity) to yellow (higher conductivity). This suggests that increasing the concentration of the substance at lower temperatures enhances the material's thermal conductivity.

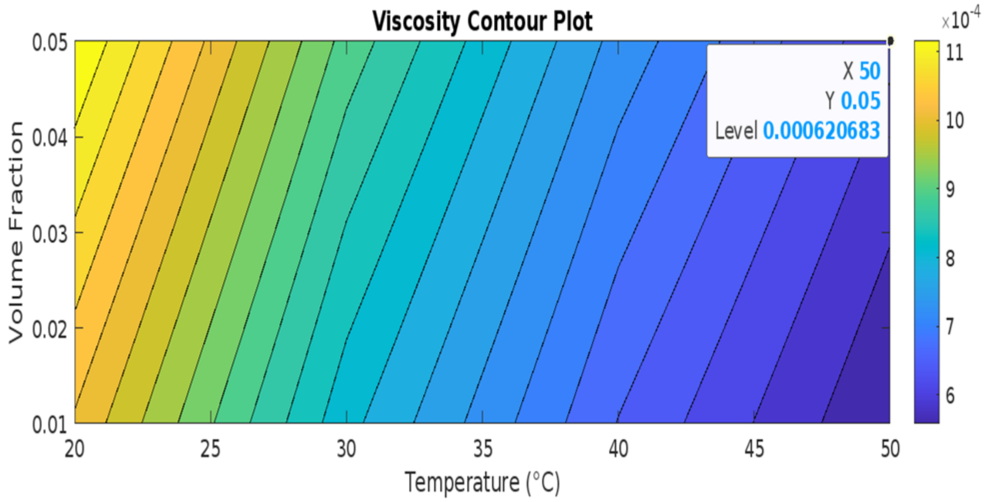

Fig 6. Viscosity with temperature and higher volume fraction

Figure 6 illustrates contour plot shows viscosity varies with temperature and volume fraction. Temperature (20°C to 50°C) is on the x-axis, and volume fraction (0.01 to 0.05) on the y-axis. The color gradient indicates viscosity, with yellow showing higher values and blue showing lower values. Viscosity decreases as temperature rises, reflecting a typical fluid behavior. Volume fraction also slightly increases viscosity, but temperature has a stronger influence overall.

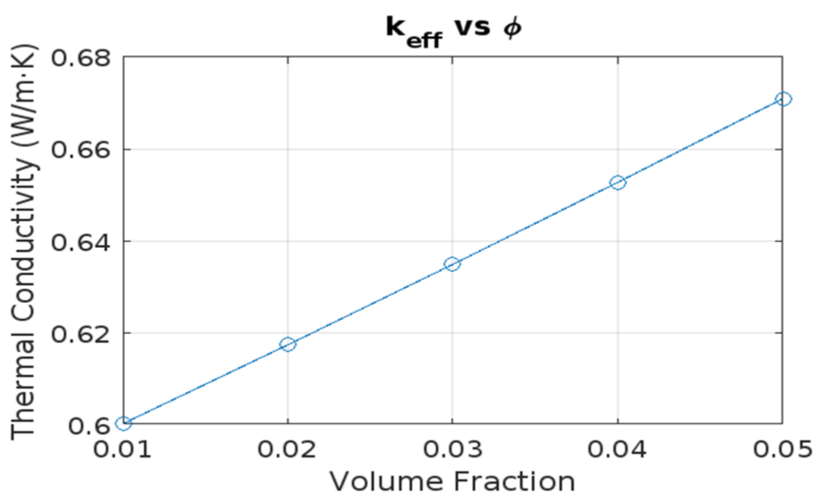

Fig 7. Thermal conductivity vs Volume Fraction

Figure 7 displays the relationship between thermal conductivity and volume fraction, labeled as k_{eff} vs (φ). The x-axis shows volume fraction (φ) from 0.01 to 0.05, and the y-axis represents thermal conductivity, ranging from 0.60 to 0.68. This plot shows a linear increase in thermal conductivity as volume fraction increases, suggesting that as more material is added to the mixture, the thermal conductivity improves. This direct relationship is common in composites or mixtures where the addition of conductive material enhances overall thermal properties.

Figure 8 illustrates the relationship between viscosity and temperature, labeled as μ_{eff} vs Temperature. The x-axis represents temperature in degrees Celsius, ranging from 20°C to 50°C, while the y-axis shows viscosity in scaled by $\times 10^{-4}$ and ranging from 5 to 11. The graph reveals an inverse relationship between temperature and viscosity, with viscosity decreasing as

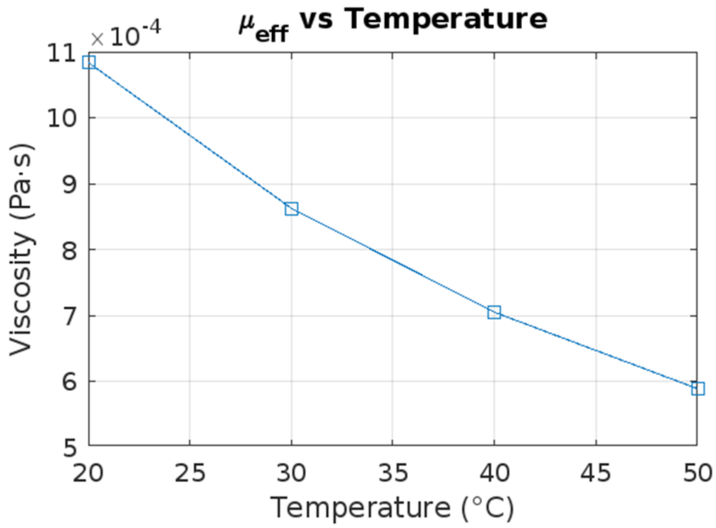

Fig 8. Viscosity vs Temperature

temperature increases. This trend aligns with the typical behavior of fluids, where higher temperatures reduce intermolecular forces, making the fluid less viscous.

4 Conclusion

Using numerical simulation, the convective heat transport of an Al_2O_3/water nanofluid through a radiator under constant inlet temperature conditions was examined. It was investigated how different parameters affected the thermal conductivity of nanofluids. The following are the main conclusions.

1. At different temperatures *50°C, 60°C and 70°C*, the concentration of nanoparticles and the mass flow rate both increase the heat transfer rate with varying volumetric concentrations.
2. As Al_2O_3 concentration increases from 0.2% to 5%, the enhancement ratio decreases with higher nanoparticles concentration.
3. Increasing the concentration of the substance at lower temperatures enhances the material's thermal conductivity.
4. Viscosity decreases with higher temperatures, as particles move more freely, and increases with higher volume fractions due to greater particle interaction.
5. Thermal conductivity increases linearly as volume fraction increases, viscosity decreasing as temperature increases.

Thus, Nanofluids are the best alternative for conventional fluids for improving heat transfer properties in IC Engines. Also, the size of IC Engine can be reduced when nanofluids are used.

References

1) Sarwe DU, Raj AS, Kumar P, Salahshour S. A novel analysis of the fractional Cauchy reaction-diffusion equations. *Indian Journal of Physics*. 2024. https://doi.org/10.1007/s12648-024-03411-0.
2) Sarwe DU, Sharma V, Gaur PK, Raj AS. An analysis of annular fin's thermal conductivity and heat production using the DTM-Pade approximation. *Computational Analysis and Applications*. 2024;33(1):178–202. https://doi.org/10.1142/S2591728524500086.
3) Alhassan ST, Ahmad SS. Thermo-physical properties and heat transfer characteristics of water and anti-freezing Al2O3/CuO-based nanofluid as a coolant for car radiator. *International Journal of Heat and Mass Transfer*. 2018;118:48–57. https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.017.
4) Hussain T, Mohammad J. A numerical simulation of heat transfer enhancement using Al2O3 nanofluid. *Nanoscience & Nanotechnology*. 2018;8:43–49. doi:http://dx.doi.org/10.2174/2210681208666181108102041.
5) Farrokhi M. A review on cooling of internal combustion engine by means of nanofluids. *International Journal of Cooling Systems*. 2019;4(4):41–48. Available from: https://sciarena.com/article/a-review-on-cooling-of-internal-combustion-engine-by-means-of-nanofluids.
6) XiaoRong Z, Yi W, Kai Z, Haozhong H. Comparison of heat transfer performance of ZnO-PG, α-Al2O3-PG, and γ-Al2O3-PG nanofluids in car radiator. *Nanomaterials and Nanotechnology*. 2019;9:1–12. https://doi.org/10.1177/1847980419868734.
7) Mohsen SR, Hosam SE, Youssef AA, Mohamed SE. On heat transfer enhancement in diesel engine cylinder head using γ-Al2O3/water nanofluid with different nanoparticle sizes. *Advances in Mechanical Engineering*. 2020;12(1):1–10. https://doi.org/10.1177/1687814020917118.

8) Razak NFD, Sani MSM, Azmi WH. Heat Transfer Augmentation in Heat Exchanger by using Nanofluids and Vibration Excitation - A Review. *International Journal of Automotive and Mechanical Engineering (IJAME)*. 2020;17(1):7719–7733. https://doi.org/10.15282/ijame.17.1.2020.19.0574.
9) Muhammad AL, Natrah K. Simulation study on the heat performance of different nanofluids for rotating detonation engine cooling. *Journal of Advanced Research in Micro and Nano Engineering*. 2021;5(1):1–8. Available from: https://akademiabaru.com/submit/index.php/armne/article/view/4447.
10) Teixeira Alves LOF, Henríquez JR, Ângelo P da Costa J, Abramchuk V. Comparative performance analysis of internal combustion engine water jacket coolant using a mix of Al2O3 and CuO-based nanofluid and ethylene glycol. *Energy*. 2022;250:123832. https://doi.org/10.1016/j.energy.2022.123832.
11) Wagd A, Renato RS, Sohel MS. Experimental investigation of heat transfer performance of Al nanofluids in a compact plate heat exchanger. *Applied Thermal Engineering*. 2023;218:119321. https://doi.org/10.1016/j.applthermaleng.2022.119321.
12) Ahmad H, Al-Khaled K, Sowayan AS, Abdullah M, Hussain M, Hammad A, et al. Experimental investigation for automotive radiator heat transfer performance with ZnO–Al2O3/water-based hybrid nanoparticles: An improved thermal model. *International Journal of Modern Physics B*. 2023;37(5):2350050. https://doi.org/10.1142/S0217979223500509.
13) Hussein AA, Auda AC, Showard AF, Dawood HI. Heat transfer enhancement by utilizing Al2O3-Water nanofluid in a coiled agitated vessel. *Case Studies in Thermal Engineering*. 2025;66. https://doi.org/10.1016/j.csite.2024.105740.
14) Abbood M, Alaiwi Y, Jundi A. Numerical Analysis and Design for Thermal Efficiency Optimization using Al2O3 Nanofluids in Shell and Tube Heat Exchangers. *CFD Letters*. 2024;16(11):146–160. https://doi.org/10.37934/cfdl.16.11.146160.
15) Baghbadorani MR, Akbari OA. Numerical investigation of heat transfer and pressure drop of water-nanofluid flow in a three-dimensional wavy mini-tube. *International Journal of Thermofluids*. 2025;25. https://doi.org/10.1016/j.ijft.2024.100998.
16) Narmatha M, Sumathi K, Selvi RP. Influence of Hall Effect and Radiation on Melting Heat Transfer of Magnetohydrodynamic Hybrid Nanofluid Flow over a Sheet with Variable Thickness. *International Research Journal of Multidisciplinary Scope*. 2025;6(1):1225–1238. https://doi.org/10.47857/irjms.2025.v0Xi0X.02815.