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Experimental Investigation of Heat Transfer Characteristics of Automobile Radiator using TiO₂ Nanofluid Coolant

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Abstract: *The use of nanoparticle dispersed coolants in automobile radiators improves the heat transfer rate and facilitates overall reduction in size of the radiators. In this study, the heat transfer characteristics of water/propylene glycol based TiO₂nanofluid was analyzed experimentally and compared with pure water and water/propylene glycol mixture. Two different concentrations of nano fluids were prepared by adding 0.1 vol. %, 0.2 vol. %, 0.3 vol. % and 0.4 vol. % of TiO₂ nanoparticles into water/propylene glycol mixture (60:40). The experiments were conducted by varying the coolant flow rate between 3 to 6 lit./min. for various coolant temperatures (50°C, 60°C, 70°C, and 80°C) to understand the effect of coolant flow rate on heat transfer. The results showed that the Nusselt number of the Nano fluid coolant increases with increase in flow rate. At low inlet coolant temperature the water/propylene glycol mixture showed higher heat transfer rate when compared with Nano fluid coolant. However at higher operating temperature and higher coolant flow rate, 0.3 vol. % of TiO₂nanofluid enhances the heat transfer rate by 8.5% when compared to base fluids.*

Keywords: *Heat transfer enhancement, Propylene Glycol, Radiator, TiO₂Nanofluid coolant*

I. INTRODUCTION

The conventional heat transfer fluids for radiators such as water and ethylene glycol have poor heat transfer performance due to their low thermal conductivity. Numerous studies have been conducted to improve the heat transfer rate of the coolants. One among them was the suspension of solid metal or metal oxide nanoparticles which can improve the thermal conductivity of the coolant fluid [1]. The Nano fluids have high thermo-physical properties and can be a potential replacement for the radiator coolants. Some of the research work done so far has been summarized below. [2] Performed a heat transfer experiment with water based Nano fluid in an automobile radiator and compared the results with pure water. The Nano fluid was prepared by addition of Al₂O₃ nanoparticles in the range of 0.1-1 vol. % into the water. Liquid flow rate to radiator has been varied between 2 to 5 lit./min. and the temperature was kept in the range of 37 to 49°C. They observed an increase in heat transfer rate with the presence of Al₂O₃ nanoparticles in water and degree of heat transfer enhancement depends on the amount of nanoparticles. At 1% volume concentration 45% enhancement was recorded. An extensive review on water/ethylene glycol based Nano fluids and their applications have been done by [3]. The authors concluded that many investigations on Nano fluids with different types of nano materials and based fluids have shown that Nano fluids possess better thermal performance. They also found that heat transfer characteristics of Nano fluids were influenced by the type of base fluids, ratio of water and ethylene glycol mixture, nanoparticle material, volume concentration, nanoparticle size and flow characteristics [4] measured the overall heat transfer coefficient of copper oxide (CuO) and iron oxide (Fe₂O₃) nanoparticles suspended in water. They prepared the Nano fluids at different pH level of water to get a stable suspension of the particles. The experiment was conducted by varying the liquid side and air side Reynolds number. It is found that overall heat transfer increased by 9% with the addition of Nanoparticles [5] investigated the performance of automotive car radiator operated with Nano fluid based coolants. Ethylene glycol based copper Nano fluid is used for the study of heat transfer characteristics. The authors concluded that heat transfer rate increases with increase in nanoparticle concentration; about 3.8% of heat transfer enhancement was achieved with addition of 2% copper nanoparticles. It is also estimated that 18% of frontal area can be reduced with addition of 2% of copper nanoparticle into the coolant.[6] performed a forced convective heat transfer study in an automobile radiator with ethylene glycol and water based TiO₂nanofluid. The Nano fluid was prepared by taking 40:60 (EG:W) mixture as base fluid and dispersing TiO₂ nanoparticles at 0.1%, 0.3% and 0.5% by volume concentration.

They observed 37% enhancement in heat transfer rate at 0.5% TiO₂ when compared to base fluid.[7] conducted experiments to analyze dispersion stability and thermal conductivity of propylene glycol based Nano fluids. Aluminum oxide (Al₂O₃) and Titanium oxide (TiO₂) nanoparticles were dispersed into propylene glycol using two-step method. The authors reported that the thermal conductivity increases non-linearly with particle concentration and the nanoparticles in base fluid was stable without any sedimentation.[8],[9] studied the heat transfer characteristics of Al₂O₃/water-ethylene glycol Nano fluid coolant in automobile radiator. Heat transfer enhancement of about 37% was obtained with 0.1% of Al₂O₃ nanoparticles. They also conducted experiments with water/propylene glycol mixture as base fluid. An enhancement of 9% in the overall heat conductance was obtained with addition of 0.2% alumina nanoparticles into propylene glycol based coolant fluid. It is seen that most of the research work done so far well based on water and water/ethylene glycol base Nano fluids. Propylene glycol a non-toxic antifreeze agent is taken for the study as an alternative for ethylene glycol due to its ecofriendly characteristics. In this Research work, the heat transfer characteristics of the radiator using water/propylene glycol based TiO₂nanofluid coolant was analyzed experimentally. Heat transfer rate and the Nusselt number behavior of the Nano fluid was compare with pure water and base coolant fluid mixture.

II. EXPERIMENTAL METHODOLOGY

A. Experimental Setup

The heat transfer rate of the nanofluid coolant was measured using an experimental setup as shown in Fig. 1. It consists of a car radiator, an electric heater, a reservoir tank, a centrifugal pump, an air blower, flow control valves and K-type thermocouples to measure inlet and outlet fluid temperature. An electrical heater of 2 kW was used to heat the coolant in the reservoir tank. The coolant was circulated using a 0.5 HP centrifugal pump. A globe valve was used to vary the flow rate of the coolant fluid entering the radiator in between 3-6 lit/min. Two K-type thermocouples were placed at the inlet and the outlet of the radiator to measure the coolant temperatures. Thermocouples were also fixed on both the sides of the radiator wall surface to measure air temperatures. 2.2 Experimental Procedure The forced convective heat transfer experiment was conducted in the radiator experimental setup using pure water, water/propylene glycol mixture (70:30), and water/propylene glycol/TiO₂nanofluid (0.1% and 0.3% by volume). The coolant in the reservoir tank was heated up to the desired temperature and circulated through the radiator using the pump. The inlet temperature of the coolant to the radiator is kept constant at the nominal operating temperature range between 50°C to 80°C. The coolant flow rate was varied between 3 to 6 l/min. The air flow rate to the radiator was kept constant at an average of 4m/s. The outlet temperature of the coolant was recorded using K-type thermocouple. Furthermore K-type thermocouples were fixed on the radiator wall on both the sides to record the air temperature.

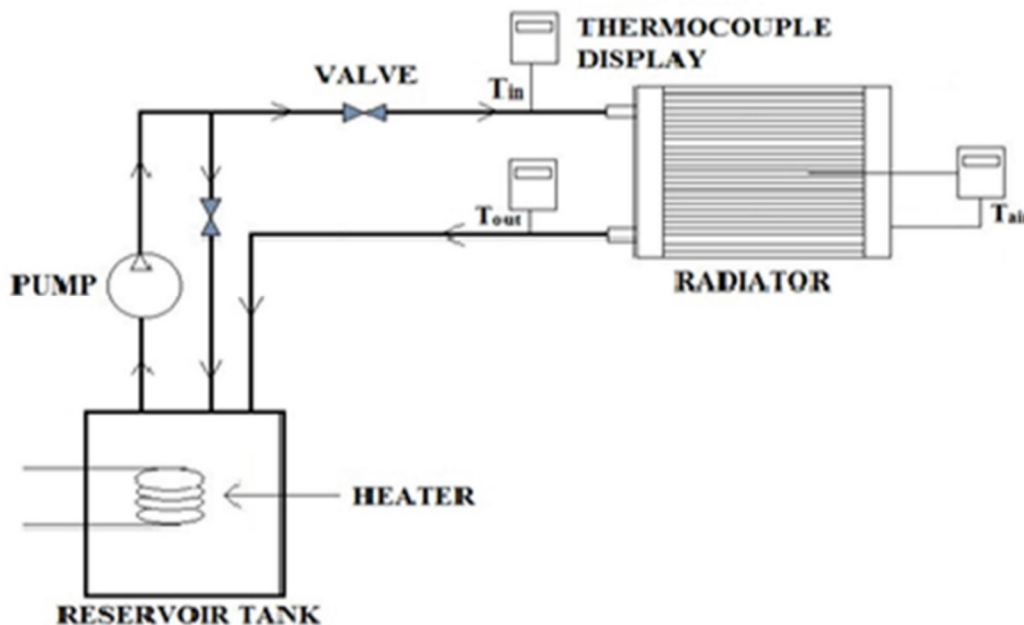


Fig. 1 Schematic view of experimental setup

III. NANOFLUID PREPARATION

Titanium dioxide (TiO₂) Nano fluid was prepared in two different concentrations 0.1%, 0.2%, 0.3% and 0.4% by volume of the base fluid using two-step method to understand the effects of particle concentration on heat transfer rate. The base fluid was the mixture of water and propylene glycol in the ratio 60:40. The dry nanoparticles were added directly in the base fluid at required concentrations. The dispersion process was carried out using probe ultrasonicator ENUP250. The Nano fluid was subjected to ultrasonication in the frequency of 20Hz for the duration of 6 hours. The density, specific heat and thermal conductivity of nanofluid were calculated using two phase flow equations [10], [11]

$$\rho_{nf} = \phi \rho_p + (1 - \phi) \rho_{bf} \quad (1)$$

$$C_{p,nf} = (1 - \phi) \left(\frac{\rho_b}{\rho_n} \right) C_{p,bf} + \left(\frac{\rho_p}{\rho_n} \right) C_{p,p} \quad (2)$$

ϕ is the volume concentration and ρ is the density.

$$k_{nf} = \frac{k_p + (\phi - 1)k_b - \phi(\phi - 1)(k_b - k_p)}{k_p + (\phi - 1)k_b + \phi(k_b - k_p)} k_{bf} \quad (3)$$

k is the thermal conductivity and ϕ is the shape factor of the nanoparticles

IV. HEAT TRANSFER CALCULATIONS

The heat transfer rate and the Nusselt number of the coolant were calculated by the following procedure. According to Newton's law of cooling.

$$Q = hA_s(T_b - T_s) \quad (4)$$

Where h is the overall heat transfer coefficient and A_s is the surface area of the tube, T_b is the bulk temperature.

$$T_b = \frac{T_{i1} + T_{o1}}{2}, \quad T_{in} \& \quad T_{out} \quad (5)$$

are the inlet and outlet temperatures of the coolant.

T_s is the tube wall temperature, obtained by the average of both the side thermocouples.

$$T_s = \frac{T_{11} + T_{12} + T_{21} + T_{22}}{4} \quad (6)$$

Heat transfer rate is given by

$$Q = mC_p(T_{i1} - T_{o1}) \quad (7)$$

Where m is the mass flow rate of the coolant and C_p is the specific heat

The overall heat transfer coefficient can be obtained from the equation (4) & (7)

$$h_{exp} = \frac{mC_p(T_{i1} - T_{o1})}{A_s(T_b - T_s)} \quad (8)$$

Nusselt number can be calculated by

$$Nu = \frac{h_e \times Dh}{k} \quad (9)$$

Dh is the hydraulic diameter of the flat tube and k is the thermal conductivity of coolant fluid

V. RESULT AND DISCUSSION

A. Effect of Flow Rate on Nusselt Number

The comparison of Nusselt number among TiO₂nanofluid and base fluid at different temperatures and mass flow rate was shown in Fig. 2. It was observed that the Nusselt number. Increases with increase in mass flow rate for both base fluid and Nanofluid concentrations. Initially at 50°C of coolant inlet conditions the water/propylene glycol mixture has highest Nusselt number. The nanoparticles did not have much influence on the Nusselt number at lower inlet temperatures. The Nusselt number of Nanofluids increases gradually with inlet temperature and at 80°C the Nanofluid with 0.3% TiO₂ has highest Nusselt number as shown in Fig. 2 (d).

This shows that the TiO₂nanofluids have good conduction to convective ratio at higher temperature and flow rate. The particle concentration in Nanofluid shows that, at 0.1% the Nusslet number does not show improvement when compared to water/propylene glycol mixture. When concentration increases to 0.3% the Nusslet number also increases above that of the base fluid.

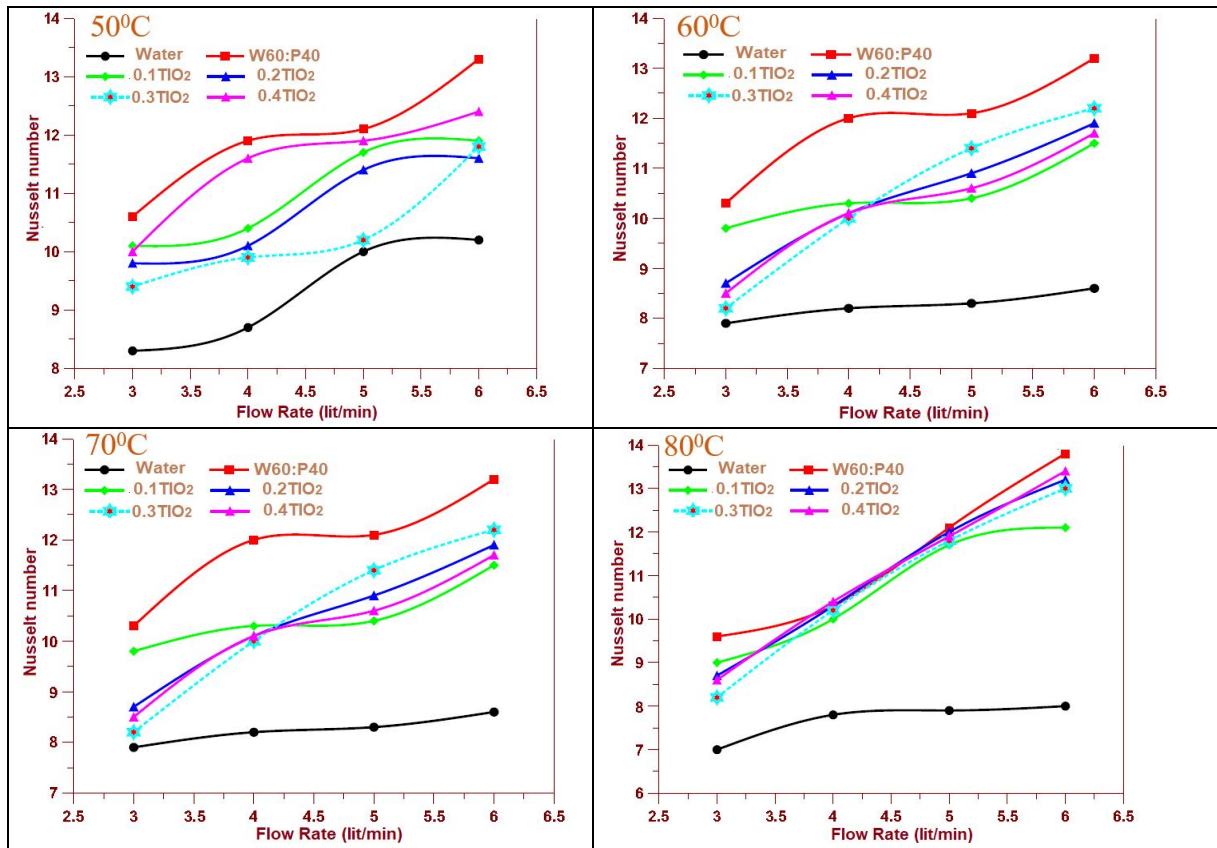
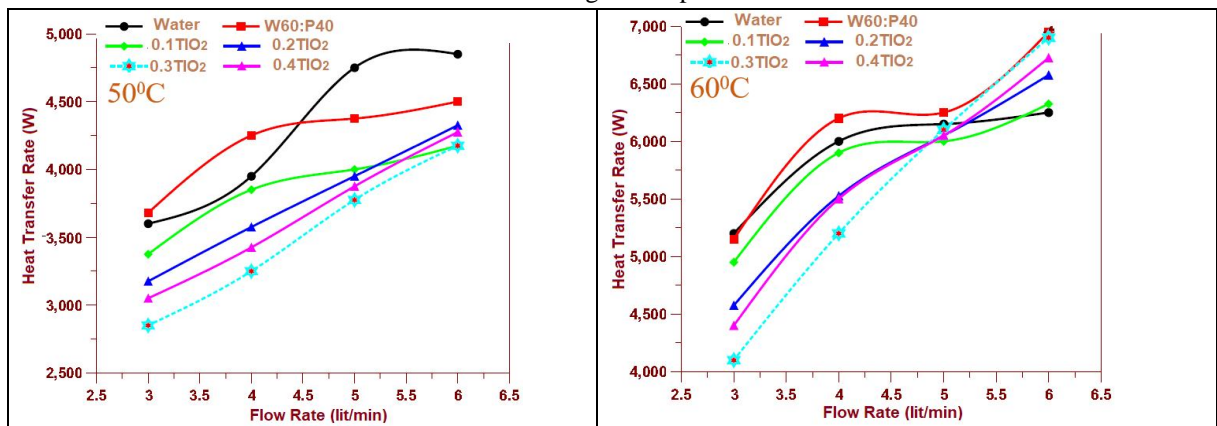


Fig. 2 Effect of flow rate on Nusselt number (a) at 50°C (b) at 60°C (c) at 70°C (d) at 80°C.

B. Effect of flow rate on Heat Transfer rate

The heat transfer rate of TiO₂nanofluid coolant was compared with pure water and water/propylene glycol mixture. Fig. 3 illustrates that heat transfer rate of TiO₂nanofluid increases with increase in volume flow rate. Initially at lower inlet temperature at 50°C the water and propylene glycol mixture shows higher heat transfer rate than Nanofluids this was due to the high specific heat capacity and low density of water and base fluid mixture. When inlet temperature increases the heat transfer rate of Nano fluid gradually increases due to the Brownian motion of nanoparticles. The density of coolant fluid decreases at higher temperature so that the random motion of nanoparticles increases and the particle comes in contact with surface of the fins which leads to increase heat transfer rate. Fig. 3 (d) shows that at 80°C of inlet conditions the Nano fluid with 0.3% TiO₂ has highest heat transfer rate. Therefore heat transfer enhancement in TiO₂nanofluid occurs at higher temperature and flow rate.



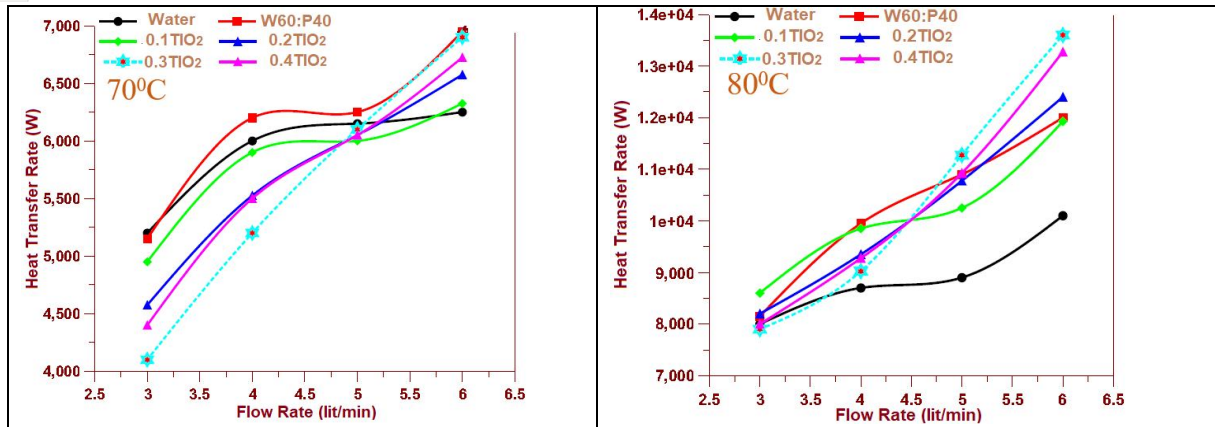


Fig. 3 Effect of flow rate on heat transfer rate (a) at 50°C (b) at 60°C (c) at 70°C (d) at 80°C.

VI. CONCLUSION

The forced convective heat transfer experiment have been performed in an automobile radiator using pure water, water/propylene glycol mixture and water/propylene glycol/TiO₂nanofluid at four different concentrations and the following conclusions were obtained.

- A. The experimental results shows that the Nusselt number behavior of the nanofluid was highly depend on the volume flow rate and a highest Nusslet number of 14.4 have been observed at 6 lit/min flow rate at 80°C inlet temperature.
- B. The Nusslet number enhancement of 8.3% was obtained by addition of 0.3% of TiO₂ nanoparticles in the base coolant mixture.
- C. Heat transfer rate increases with increase in nanoparticles concentration at higher operating temperatures and coolant flow rate.
- D. The heat transfer enhancement of about 8.5% was achieved with addition 0.3% of TiO₂ nanoparticles at 80°C coolant inlet temperature.
- E. The results shows that the nanofluid coolants have tendency to remove heat from the engines at higher operating temperatures and flow rate effectively which makes it suitable for heavy duty engines.

VII. ACKNOWLEDGMENT

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