Heat transfer characteristics of car radiator using tri-hybrid nanocoolant

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Abstract. The use of nanoparticle coolant fluid in the car radiator increases the rate of heat transfer and facilitates the reduction of the overall radiator size. In this study, heat transfer characteristics of Al\textsubscript{2}O\textsubscript{3}-TiO\textsubscript{2}-SiO\textsubscript{2} nanofluids-based water/ethylene glycol were analysed experimentally and compared with water/ethylene glycol mixture. Four different nanofluids concentrations were prepared by adding 0.05 to 0.3 vol.\% of tri-hybrid nanofluid nanoparticles dispersed a mixture of water/ethylene glycol (60:40). Experiments were carried out by varying the flow rate of coolant between 2 to 12 LPM for working temperature of 70 °C, the velocity of airflow remained at an average of 4 m/s in order to analyse the effect of coolant flow rate on heat transfer. The results showed that the heat transfer coefficient of Al\textsubscript{2}O\textsubscript{3}-TiO\textsubscript{2}-SiO\textsubscript{2} nanofluids or tri-hybrid nanofluids increased with increasing volume concentrations and temperatures. The maximum enhancement of the heat transfer coefficient for coolant side is observed at 39.7\% at 0.3\% volume concentration. The pressure drop and pumping power have the same pattern which increasing in volume concentrations, the pressure drop and pumping power will increase due to the concentration of the nanofluids. The correlation is applicable for water/ethylene glycol (60:40) mixture and Al\textsubscript{2}O\textsubscript{3}-TiO\textsubscript{2}-SiO\textsubscript{2} nanofluids with volume concentrations of 0.05 to 0.3\% at 70 °C working temperature.

1. Introduction

Conventional coolants had been widely hired to deplete heat in the majority of the engineering programs. Ordinary coolants consist of count number in all three states particularly solid, liquid and gas based totally at the requirements of the application and possible mode of heat transfer. However, with the modern technological improvements, an emerging magnificence of new coolants particularly nano-coolants (coolants with dispersed nanoparticles) find their applications in a variety of engineering applications [1-4].

New nanofluid applications use it as a replacement for conventional cooling in a car radiator, an important component of a car engine. Radiator serves as a heat exchanger for conventional car engine cooling using water as an exchange media. The thermal performance of a vehicle engine under the influence of nanofluid has been studied by many researchers, and the main application of nanofluid is...
as coolant and lubricant on the car radiator in an effort to improve the efficiency of heat removal. Results show that the heat transfer coefficient can be increased by more than 50% compared to conventional cooling but limited by a decrease in fluid pressure. However, experts may conclude that optimal performance can be achieved in low nano-particle volume fraction less than 1% (v <1%) [5].

Heris et al. [6] and Peyghambarzadeh et al. [7] have experimentally investigated the performance of metal oxide with water/Ethylene Glycol as a coolant in vehicle radiator. They found that increased heat transfer turned into observed growth during the overall performance of basic fluids. Similarly to Naraki et al. [8] used CuO/water nanofluid in an automobile radiator. Under laminar flow conditions they investigated nanofluid performance with a concentration of 0.15-0.4%. The overall heat transfer coefficient with nanofluid changes to be determined 6-8% more than water. Leong et al. [9] studying the overall performance of ethylene glycol mainly nanofluid based copper as a coolant in the vehicle radiator. They note that by adding 2% copper particles in EG 3.8% increase in heat transfer can be obtained from ethylene glycol under cooling turbulent flow situation. Ebrahim et al. [10] conducted an experimental heat transfer study in a car radiator with nanofluid SiO$_2$ water. They find that the Nusselt range will increase as the temperature of the inlet is cooled, the Reynolds and the volume fraction increase.

In regarding on shape and measurement of the tube models, Park and Pak [11] presented a laminar flow computing study in flat tubes with different shapes and sizes using a mixture of ethylene glycol and water. They apply their calculations in Reynolds range variation from 10 to 200, which includes fluid flow at flow rates in radiator from 18 to 75 l/min for engines with volume transfer of 1800 cc. Vajjha et al. [12] conducted a numerical study to test the thermal performance of nanoparticles of Al$_2$O$_3$ and CuO in ethylene glycol and water mixture under laminar flow conditions using a flat tube radiator of the car. The results show a massive increase of the convective heat transfer coefficient beside the flat tube for nanofluid above the base fluid. The heat transfer coefficient of Al$_2$O$_3$ nanofluid with volume concentrations is 10% greater than the base fluid with an average of about 91%. In addition, both local and average friction factors and the convective heat transfer coefficient increase with concentration of nanoparticle volume.

Leong et al. [9] investigated analytically the thermal performance of Cu/Ethylene Glycol (EG) nanofluids in an automobile radiator. They utilized records from the literature and empirical correlations to model the thermal properties. The global heat transfer coefficient for the nanofluids was 3.8% for nanofluids higher than to base fluid, for a concentration 2% and Reynolds wide variety of 6000 for the air side and 5000 for the coolant aspect. This enhancement should offer a reduction of 18.7% of the radiator frontal area, with a penalty of 12.1% within the pumping energy.

Namburu et al. [13] the numerically analyzed turbulent flow and heat transfer into several types of nanofluids are copper (CuO), alumina (Al$_2$O$_3$) and silicon (SiO$_2$) in ethylene glycol and water, flowing through circular tubes under constant heat flux. Results found that nanofluid containing tiny lower-density nanosurfer produced higher viscosity and Nusselt numbers. Nusselt numbers are also enlarged on higher particle volume fractions. It was found that at constant heat flux (50 W/cm$^2$) with a constant Reynolds number (20,000), the heat transfer coefficient of 6% CuO nanofluid has increased 1.35 times the base fluid. At the same fraction of particle volume, CuO nanofluid produces a higher heat transfer coefficient than the different types of nanofluids.

Devireddy et al. [14] conducted a forced conventional heat transfer study in a car radiator with a water-based ethylene glycol and nanofluid TiO$_2$. Nanofluid was made by taking 40:60 (EG:W) of the mixture as a basic liquid and dispersing the TiO$_2$ nanoparticles in 0.1%, 0.3% and 0.5% based on volume concentration. They observed a 37% increase in the rate of heat transfer at 0.5% TiO$_2$ when compared to base fluid. Nambeesan et al. [15] studying characteristics of heat transfer Al$_2$O$_3$/water-ethylene glycol cooling in the car radiator. Increased heat transfer of about 37% was obtained with 0.1% Al$_2$O$_3$ nanowires. The authors also conducted experiment with a mixture of water/propylene glycol as a basic liquid. The increase of 9% in overall heat conductance was obtained by adding 0.2% alumina nanoparticles into a propylene glycol based coolant liquid. In addition, various experimental
works were conducted to investigate the heat transfer performance of nanofluids for various cooling applications [16].

The objective of this study is to investigate of the heat transfer characteristics of the radiator using water/ethylene glycol based tri-hybrid nanofluids with a volume concentration of 0.05-0.3% as coolant was analysed experimentally in automotive radiator setup. Characteristics of heat transfer and behaviour of decreased nanofluid pressure compared to a mixture of base coolant fluid.

2. Methodology

2.1. Material

The preparation of tri-hybrid nanofluids involved three different types of single nanofluids namely Al$_2$O$_3$, TiO$_2$ and SiO$_2$ mixed together and dispersed in the base fluid of water/EG mixture. All the single nanofluids were procured from US Research Nanomaterials, Inc. The respective nanoparticles size for Al$_2$O$_3$, TiO$_2$ and SiO$_2$ are 13, 50 and 23 nm with a purity of 99.8%, 99% and 99.99%. The properties of each nanoparticle types are given in table 1. The base fluid used in the present study was a mixture of water and EG at a ratio of 60:40 (vol.%). Meanwhile, the properties of ethylene glycol is tabulated in table 2.

Table 1. Properties of Al$_2$O$_3$, TiO$_2$ and SiO$_2$ nanoparticles [17, 18].

| Properties                        | Al$_2$O$_3$ | TiO$_2$ | SiO$_2$ |
|-----------------------------------|------------|---------|---------|
| Molecular mass, g mol$^{-1}$      | 101.96     | 79.86   | 60.08   |
| Average particle diameter, nm     | 13         | 50      | 23      |
| Density, kg m$^{-3}$              | 4000       | 4230    | 2220    |
| Thermal conductivity, W m$^{-1}$ K$^{-1}$ | 40         | 8.4     | 1.4     |
| Specific heat, J kg$^{-1}$ K$^{-1}$| 773        | 692     | 745     |

Table 2. Properties of Ethylene Glycol (EG) [19].

| Properties                        | EG       |
|-----------------------------------|----------|
| Vapour pressure, mmHg at 20 °C    | 0.08     |
| Boiling point, °C                 | 195–198  |
| Melting point, °C                 | -13      |
| Density, g ml$^{-1}$ at 25 °C     | 1.113    |

2.2. Preparation of tri-hybrid nanofluids

Two-step method is used for the preparation of tri-hybrid nanofluids. Tri-hybrid nanofluids are prepared by mixing the three nanofluids (Al$_2$O$_3$, TiO$_2$ and SiO$_2$) together, undergoing mixing and sonication based processes by Ramadhan et al. [20]. Preparation of nanofluids initially begins with the volume calculations required in accordance with concentration. In this study, tri-hybrid nanofluides were prepared at volume concentrations of 0.05, 0.1, 0.2, and 0.3%. Nanofluid was first prepared at the highest concentrations of 0.3% and then diluted to a lower concentration.

Single nanofluids Al$_2$O$_3$, TiO$_2$ and SiO$_2$ are supplied in water suspensions with a weight concentration of 20, 40, 25% for Al$_2$O$_3$, TiO$_2$ and SiO$_2$ respectively. Equation (1) [21, 22] is used to convert from weight concentration to volume concentration. The dilution from higher volume concentration to lower volume concentration utilized the equation (2) [19] by adding the base fluid ($\Delta V$).

$$\phi = \frac{\omega \rho_w}{100 \rho_w + \left(1 - \frac{\omega}{100}\right) \rho_p}$$  

(1)
\[
\Delta V = (V_2 - V_1) = V_1 \left( \frac{\phi_1}{\phi_2} - 1 \right)
\]  

(2)

All single nanofluids are mixed together at a ratio of 1/3: 1/3: 1/3 to form tri-hybrid nanofluid. Total volume of 100 ml is prepared for each tri-hybrid nanofluid concentration. The combined solutions of the three single nanofluids of Al\textsubscript{2}O\textsubscript{3}, TiO\textsubscript{2} and SiO\textsubscript{2} were mixed together using a magnetic stirrer for 120 minutes. Then, the solution undergoes a sonication process using ultrasonic bath to increase stability.

2.3. **Automotive radiator setup**

The heat transfer performance of nanofluid coolers is measured by experimental use in automotive radiator settings as shown in figure 1. It consists of car radiator, heater storage tank, centrifugal pump, fan blower, flow control valves and thermocouple K-type to measure fluid temperature incoming and outgoing channels. 3.3 kW electric heaters are used to heat the coolant in the reservoir tank. Coolant is distributed using centrifugal pump 1.0 HP. The control valve in the pump is used to vary the flow rate of the coolant fluid into the radiator between 2-12 LPM. Two K-type thermocouples are placed in the inlet and radiator outlet to measure the coolant fluid temperature. Thermocouples are also installed on both sides of the radiator wall surface to measure the air temperature and radiator tubes. The radiator specification as shown in table 3.

2.4. **Automotive radiator procedure**

The experimental heat transfer was performed in radiator experiments preparation of water/EG (60:40) and tri-hybrid nanofluids with volume concentration of 0.05 - 0.3%. The coolant in the collection tank with volume 17 litre is heated to the desired temperature and circulated through the radiator using the pump. The temperature of the coolant inlet to the radiator is maintained constant at nominal operating temperature from 60 to 70 °C. The cooling flow rate varies between 2 to 12 LPM. The air flow rate to the radiator is maintained constant at an average of 4 m/s. The temperature of the cooling outlet is recorded using the K-type thermocouple. Furthermore, the K-type thermocouple remains on the radiator wall on both sides to record air temperature and temperature wall tube.

![Figure 1. Automotive radiator setup.](image-url)
Table 3. Components of automotive radiator setup.

| Main Section      | Description                                                                 | Function                                                                 |
|-------------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Radiator          | Dimension radiator: 34.0 mm × 1.3 mm × 36.8 mm n: 32 vertical aluminum tubes | Test section for the heat transfer analysis.                              |
| Data logger       | ADAMView Advantech Data Acquisition                                       | To record the experimental data of temperature and pressure             |
| Fan               | Range: 0 to 1250 RPM                                                      | For the cooling process of the system.                                   |
| Heater storage tank | Volume: 17 litre                                                          | To store the nanofluid.                                                 |
| Pump              | 1.0 HP                                                                     | To circulate working nanofluid to the whole system.                     |
| Pressure transducer | Differential type, 5.0 psi                                               | To measure pressure drop of the fluid flow.                             |
| Flow rate meter   | Range: 2.0 to 14.0 LPM                                                    | To measure the fluid flow rate.                                         |

2.5. Nanofluid thermo physical properties

The density ($\rho_{nf}$) and specific heat capacity ($C_{p,nf}$) of tri-hybrid nanofluids are obtained by the relation equations (3) and (4) [20].

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \phi(R\rho)_{Al_{2}O_{3}} + \phi(R\rho)_{TiO_{2}} + \phi(R\rho)_{SiO_{2}}$$ (3)

$$C_{p,nf} = \frac{(1 - \phi)\rho_{bf}C_{bf} + \phi(R\rho C)_{Al_{2}O_{3}} + \phi(R\rho C)_{TiO_{2}} + \phi(R\rho C)_{SiO_{2}}}{\rho_{nf}}$$ (4)

Table 4 presented the thermo physical properties of tri-hybrid nanofluids at 70 °C temperature for used in automotive radiator setup.

Table 4. Thermo physical properties of tri-hybrid nanofluids at temperature of 70 °C.

| $\phi$ (%) | $\rho_{nf}$ (kg/m$^3$) | $\mu_{nf}$ (Ns/m$^2$) | $C_{nf}$ (J/kg.K) | $k_{nf}$ (W/m.K) |
|-----------|------------------------|-----------------------|-------------------|------------------|
| 0.05      | 1034.59                | 0.003313              | 3631.12           | 0.465            |
| 0.1       | 1035.82                | 0.003586              | 3626.25           | 0.471            |
| 0.2       | 1038.27                | 0.003475              | 3616.55           | 0.473            |
| 0.3       | 1040.71                | 0.003712              | 3606.89           | 0.481            |

2.6. Experimental data analysis for coolant side

Parameters required for nanofluid side calculations are heat transfer coefficient, nanofluid heat capacity, pressure drop, pumping power. The mathematical formulas used for heat transfer coefficient can be expressed as equation (5).

$$h_{nf} = \frac{Nu_{nf}k_{nf}}{D_{h,nf}}$$ (5)

where $k_{nf}$ is obtained from Eastman et al. [23]. The nusselt number for nanofluid is expressed by equation (6) as implemented by Hamid et al. [18].

$$Nu_{nf} = 0.0247Re^{0.8}Pr^{0.4}\left(1 + \frac{\phi}{100}\right)^{6.29}$$ (6)

The Reynolds number (Re) expression in equation (6) for nanofluid is given by equation. (7).
\[ \text{Re}_{nf} = \frac{G_{nf} D_{h,nf}}{\mu_{nf}} \]  

(7)

Parameter \( G_{nf} \) is define as the Core mass velocity of coolant that can be expressed as equation (8):

\[ G_{nf} = \frac{W_{nf}}{A_f \sigma_{nf}} \]  

(8)

The heat capacity rate, \( C_{nf} \) can be expressed as equation (9).

\[ C_{nf} = W_{nf} C_{p,nf} \]  

(9)

Meanwhile, pressure drop, \( \Delta P_{nf} \) can be expressed as equation (10).

\[ \Delta P_{nf} = \frac{G_{nf}^2 \times f_{nf} \times H}{2 \times \rho_{nf} \times \left( \frac{D_{h,nf}}{4} \right)} \]  

(10)

where the friction factor correlation of nanofluid is given equation (11) by Hamid et al. [18],

\[ f_{nf} = 0.3164 \times (\text{Re}_{nf})^{-0.25} \left( \frac{\rho_{nf}}{\rho_{bf}} \right)^{0.797} \left( \frac{\mu_{nf}}{\mu_{bf}} \right)^{0.108} \]  

(11)

The pumping power can be expressed as equation (12).

\[ P = \left( \frac{W_{nf}}{\rho_{nf}} \right) \Delta P_{nf} \]  

(12)

3. Results and discussion

3.1. Heat transfer performance

Figure 2 and figure 3 illustrate the heat transfer coefficient and Nusselt number of \( \text{Al}_2\text{O}_3-\text{TiO}_2-\text{SiO}_2 \) nanofluids at 70 °C. It can be observed that the experimental data for \( \text{Al}_2\text{O}_3-\text{TiO}_2-\text{SiO}_2 \) nanofluids is in good agreement with the data trend given by Dittus and Boelter [24] and the base fluid. The Reynolds number was influenced by the increasing of heat transfer coefficient and Nusselt number by 39.7% maximum enhancement occurs at 0.3% whereas 45% enhancement occurs at concentration 0.3%. However, all of the concentration is higher than the base fluid in the pattern. The increasing of temperature, volume concentration and Reynolds number were enhanced the heat transfer and Nusselt number. At 70 °C the range of Reynolds number is higher up to 5000. This happened due to the decreasing of viscosity because of the higher temperature. The higher of thermal properties would improve the heat transfer coefficient.
Figure 2. Heat transfer coefficient of Al2O3-TiO2-SiO2 nanofluids at working temperature 70 °C.

Figure 3. Nusselt number of Al2O3-TiO2-SiO2 nanofluids at working temperature 70 °C.

3.2. Pressure drop and pumping power

Figure 4 and figure 5 present pressure drops and pumping power from the Al2O3-TiO2-SiO2 nanofluids at 70 °C working temperature. The pressure drop and pumping power of the tri-hybrid nanofluids increased with increasing volume concentration. This is because at higher volume concentration, the viscosity of the nanofluids will also increase. Therefore it will cost pressure and power to increase in the system. The highest pressure drop observed was at 0.3% volume concentration with 180 kPa. Meanwhile for the pumping power, the highest was also observed at 0.3% with 0.035 kW of power. The lowest pressure drop and pumping power could be observed at 0.05% volume concentration with 5 kPa and 0.001 kW. Indicates that all concentrations are above the base fluid which is increased from the base fluid.
Figure 4. Pressure drop of Al$_2$O$_3$-TiO$_2$-SiO$_2$ nanofluids at working temperature 70 °C.

Figure 5. Pumping power of Al$_2$O$_3$-TiO$_2$-SiO$_2$ nanofluids at working temperature 70 °C.

4. Conclusion
In the present study, thermal performance of Al$_2$O$_3$-TiO$_2$-SiO$_2$ nanofluids in mixture water/EG (60:40) has been investigated for volume concentrations of up to 0.3% and working temperature of 70 °C. The heat transfer coefficient of Al$_2$O$_3$-TiO$_2$-SiO$_2$ nanofluids increases with increasing volume concentration and temperature. The maximum enhancement of the heat transfer coefficient for coolant side is observed at 39.7% at 0.3% volume concentration. The pressure drop and pumping power have the same pattern which increases in volume concentrations, the pressure drop and pumping power will increase due to the concentration of the nanofluids. The correlation is applicable for water/EG (60:40) mixture and Al$_2$O$_3$-TiO$_2$-SiO$_2$ nanofluids with volume concentrations of 0.05 to 0.3% at 70 °C working temperature.
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