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Research Paper

Experimental Investigation of Cooling Performance in Automotive Radiator using Al_2O_3-TiO_2-SiO_2 Nanofluids

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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 tri-hybrid nanofluids-based water/EG (60:40) were analyzed experimental and compared with water/EG (60:40). Four different nanofluids concentrations were prepared by adding 0.05 to 0.3 vol.% of tri-hybrid nanofluids 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, to understand the effect of coolant flow rate on heat transfer. The results showed that the thermal performance of tri-hybrid nanofluids in a water/EG (60:40) mixture has been investigated for volume concentrations of up to 0.3% and working temperature of 70 °C. The maximum enhancement of heat transfer coefficient for air side is observed up to 23.8% at 0.05% volume concentration meanwhile 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.

Keywords: Cooling performance; Heat transfer coefficient; Pressure drop; Radiator; Tri-hybrid nanofluid

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 [1-7].

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 [8-10]. 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% (u <1%) [11].

Heris et al. [12] and Peyghambarzadeh et al. [13] have experimentally investigated the performance of metal oxide with EG-water 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. [14] 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. [15] studied 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. Ebrahimi et al. [16] 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 [17] 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. [18] conducted a numerical study to test the thermal performance of nanoparticles of Al_2O_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_2O_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. [15], investigated analytically the thermal performance of Cu/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. [19] numerically analysed turbulent flow and heat transfer with several types of nanofluids. They studied copper (CuO), alumina (Al_2O_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. [20] 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. [21] studied characteristics of heat transfer Al_2O_3/water-ethylene glycol cooling in the car radiator. Increased heat transfer of about 37% was obtained with 0.1% Al_2O_3 nanowires. They also 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.

Lai et al. [22] studied nanofluid flow behavior (Al_2O_3-water; 20 nm) in millimetre-sized stainless steel tubes, undergo constant wall heat flux and low Reynolds (Re <270). The increase of the maximum Nusselt amount of nanofluid 8% at a concentration of 1 vol.% was recorded. Jung et al. [23] conducted a convective heat transfer experiment for nanofluid (Al_2O_3-water) in rectangular microchannel under laminar flow conditions. The convective heat transfer coefficient increased by more than 32% to 1.8 vol.% nanoparticles in base fluid. The number of Nusselt increases with the increasing number of Reynolds in the laminar flow regime (5 <Re <300) and the new convective heat transfer correlation for nanofluids in the micro channel is also proposed.

Sharma et al. [24] applied 12.5 vol% Al_2O_3 in water in horizontal tube geometry and concludes that at 3500 and 6000 to 41% of Pe promotions in the heat transfer coefficient compared to pure water can occur. Ho et al. [25], conducted experiments for cooling in horizontal tubes in Al_2O_3-water laminar flow at concentrations of 1 and 2 vol% and concluded an interesting increase of 51% in heat transfer coefficient. Nguyen et al. [26] conducted their experiments on radiator heaters and at 6.8 vol% Al_2O_3 in water obtained a 40% increase in heat transfer coefficient. Another reviews on nanofluid heat transfer have also been published in literature [27-30]. Interested readers may refer them to the full review of previous studies conducted.

In this study, 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. The characteristics of heat transfer for coolant side and fin efficiency air side and behaviour of nanofluid pressure were compared to a mixture of base coolant fluid.

2. Method

2.1. *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_2O_3, TiO_2 and SiO_2) together, undergoing mixing and sonication based processes by Ramadhan et al. [16,49]. Preparation of nanofluids initially begins with the volume calculations required in accordance with concentration. In this study, tri-hybrid nanofluids 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_2O_3, TiO_2 and SiO_2 are supplied in water suspensions with a weight concentration of 20, 40, 25% for Al_2O_3, TiO_2 and SiO_2 respectively. All single nanoparticle were obtained from US Research Nanomaterials, Inc. The nanoparticle sizes for Al_2O_3, TiO_2 and SiO_2 were 13, 50 and 22 nm with 99.8% purity, 99% and 99.99%. Eq. (1) [30-32] is used to convert from weight concentration to volume concentration. The dilution from higher volume concentration to lower volume concentration utilized the Eq. (2) [31] by adding the base fluid (ΔV).

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

$$\Delta V = (V_2 - V_1) = V_1\left(\frac{\phi_1}{\phi_2} - 1\right) \tag{2}$$

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_2O_3, TiO_2 and SiO_2 were mixed together using a magnetic stirrer for 120 minutes. Then, the solution undergoes a sonication process using ultrasonic bath to increase stability.

2.2. *Measurement of thermal conductivity and dynamic viscosity*

The nanofluids thermal properties were measured experimentally in the Advance Automotive Liquids Laboratory at University Malaysia Pahang. The nanofluids thermal conductivity is measured by KD2 Pro thermal properties analyzer from Decagon Devices, Inc., USA. It should be noted that many researchers have used KD2 pro in their thermal conductivity measurements such as [30, 32-37, 50-52]. The thermal conductivity meter is hotwire while KD2 Pro is used to determine the thermal conductivity of this sample. Sensors are calibrated by determining the thermal conductivity of distilled water and glycerin. Thermal conductivity measured at room temperature is 0.610 and 0.280 W/mK, respectively for distilled water and glycerin, corresponding to the values in the literature respectively of 0.613 and 0.285 W/mK, in ± 5% accuracy. Furthermore, water baths are used to maintain constant temperature in 0.1 °C. To ensure measurements in 5%, at least five measurements are performed for each concentration at a given temperature as described by Yang et al. [38] and Tso et al. [39]. Furthermore, the commercial Brookfield DV-II viscometer has been used for the measurement of nanofluids viscosity at 25 °C. First, distilled water has been used to calibrate the measurement of viscosity. Then nanofluids viscosity was measured. The hot wire method is used for the measurement of thermal conductivity and viscosity used for viscosity measurement.

2.3. *Nanofluids thermo physical properties*

The density (ρ_{nf}) and specific heat capacity ($C_{p,nf}$) of tri-hybrid nanofluids are obtained by the relation [32].

Table 1 presented the thermo physical properties of tri-hybrid nanofluids at 70 °C temperature for used in automotive radiator setup.

2.4. *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 2.

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi(R\rho)_{Al_2O_3} + \varphi(R\rho)_{TiO_2} + \varphi(R\rho)_{SiO_2} \tag{3}$$

$$C_{p,nf} = \frac{(1-\varphi)\rho_{bf}C_{bf} + \varphi(R\rho C)_{Al_2O_3} + \varphi(R\rho C)_{TiO_2} + \varphi(R\rho C)_{SiO_2}}{\rho_{nf}} \tag{4}$$

Table 1. Thermo physical properties of tri-hybrid nanofluids at temperature of 70 °C [40]

ϕ (%)	ρ_{nf} (kg/m³)	μ_{nf} (Ns/m²)	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

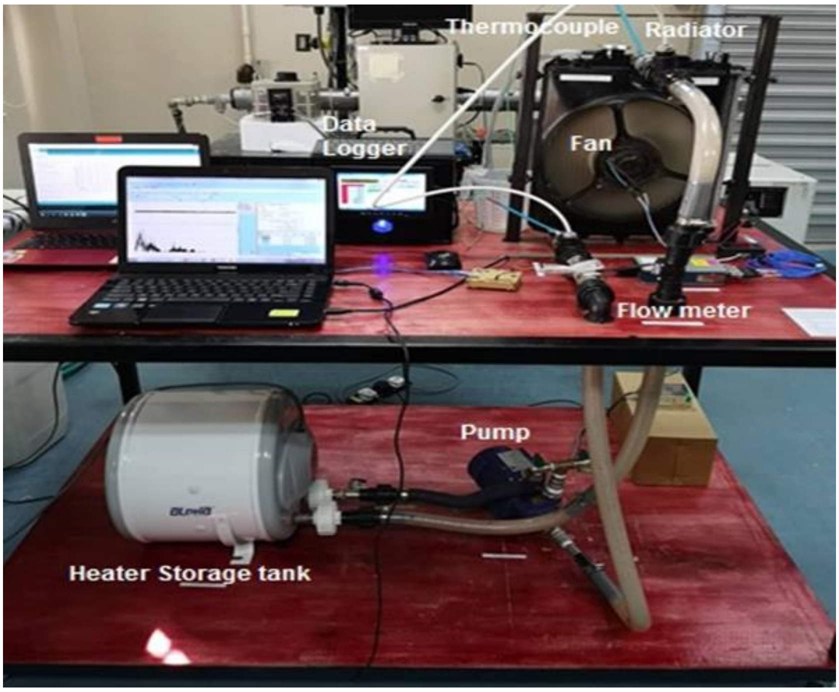


Figure 1. Automotive radiator setup [40]

Table 2. Components of automotive radiator setup [40]

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 L	To store the nanofluid.
Pump	1.0 HP	To circulate working nanofluid to the whole system.
Flow rate meter	Range: 2.0 to 14.0 LPM	To measure the fluid flow rate.

2.5. *Automotive radiator procedure*

The experimental heat transfer was performed in radiator experiments preparation of W: EG (60:40) and tri-hybrid nanofluids with volume concentration of 0.05 - 0.3%. The coolant in the collection tank with volume 17 L 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.

2.6. *Experimental data analysis*

Parameters required for nanofluid side calculations are heat transfer characteristic for coolant side and air side. The mathematical formulas used as shown below.

2.6.1. *Coolant side*

Heat transfer coefficient can be expressed as Eq. (5):

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

where k_{nf} is obtained from Eastman et al. [41]. The Nusselt number for nanofluid is expressed as Eq. (6) by Hamid et al. [42]:

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

Where, Reynolds number expression for nanofluid is given by Eq. (7),

$$\mathrm{Re}_{nf} = \frac{G_{nf} D_{h,nf}}{\mu_{nf}} \tag{7}$$

Core mass velocity of coolant is expressed as Eq. (8):

$$G_{nf} = \frac{W_{nf}}{A_{fr} \sigma_{nf}} \tag{8}$$

Heat capacity rate, C_{nf} can be expressed as Eq. (9).

$$C_{nf} = W_{nf} C_{p,nf} \tag{9}$$

Pressure drop, ΔP_{nf} can be expressed as Eq. (10),

$$\Delta P_{nf} = \frac{G^2{}_{nf} \times f_{nf} \times H}{2 \times \rho_{nf} \times \left(\frac{D_{h,nf}}{4}\right)} \tag{10}$$

Where the friction factor correlation of nanofluid is given Eq. (11) by Hamid et al. [42],

$$f_{nf} = 0.3164 \times (\mathrm{Re}_{nf})^{-0.25} \left(\frac{\rho_{nf}}{\rho_{bf}}\right)^{0.797} \left(\frac{\mu_{nf}}{\mu_{bf}}\right)^{0.108} \tag{11}$$

2.6.2. *Air side calculation*

Air heat capacity rate can be expressed as Eq. (12):

$$C_a = W_a C_{p,a} \tag{12}$$

Core mass velocity of air is given by Eq. (13):

$$G_a = \frac{W_a}{A_{fr} \sigma_a} \tag{13}$$

Heat transfer coefficient, h_a can be expressed as Eq. (14):

$$h_a = \frac{j_a G_a C_{p,a}}{\mathrm{Pr}^{2/3}} \tag{14}$$

Correlation for the Colburn j factor is given Eq. (15) by Dong et al. [43],

$$j_a = 0.26712\,\mathrm{Re}_a^{-0.1944} \times \left(\frac{L_a}{90}\right)^{0.257} \times \left(\frac{F_p}{L_p}\right)^{-0.5177} \times \left(\frac{F_h}{L_p}\right)^{-1.9045} \times \left(\frac{L_h}{L_p}\right)^{1.7159} \times \left(\frac{L_d}{L_p}\right)^{-0.2147} \times \left(\frac{t}{L_p}\right)^{-0.05} \quad (15)$$

Where Reynolds number expression for louvered fin is Eq. (16):

$$\mathrm{Re}_a = \frac{G_a u_a L_p}{\mu_a} \quad (16)$$

Fin efficiency, ηf can be expressed as Eq. (17):

$$\eta = \frac{\tanh ml}{ml},\; m = \sqrt{\frac{2h_a}{kt}} \quad (17)$$

Total surface temperature effectiveness, can be expressed as Eq. (18) by Sarkar et al. [44].

$$\eta_o = 1 - \frac{A_f}{A}(1 - \eta_f) \quad (18)$$

2.6.3. *Thermal performance calculation*

Overall heat transfer coefficient, based on air side can be expressed as bellow [15], where wall resistance and fouling factors are neglected by Eq. (19-22).

$$\frac{1}{U_a} = \frac{1}{\eta_o h_a} + \frac{1}{\left(\frac{\alpha_{nf}}{\alpha_a}\right) h_{nf}} \quad (19)$$

Number of heat transfer unit is expressed as:

$$NTU = \frac{U_a A_{fr,a}}{C_a} \quad (20)$$

Effectiveness for cross-flow unmixed fluid can be expressed as Eq. (21) by Leong et al. [15],

$$\varepsilon = 1 - \exp\left[\frac{NTU^{0.22}}{C^*}\exp(-C^* NTU^{0.78} - 1)\right] \quad (21)$$

Where $C^* = C_{min}/C_{max}$. Pumping power can be expressed as:

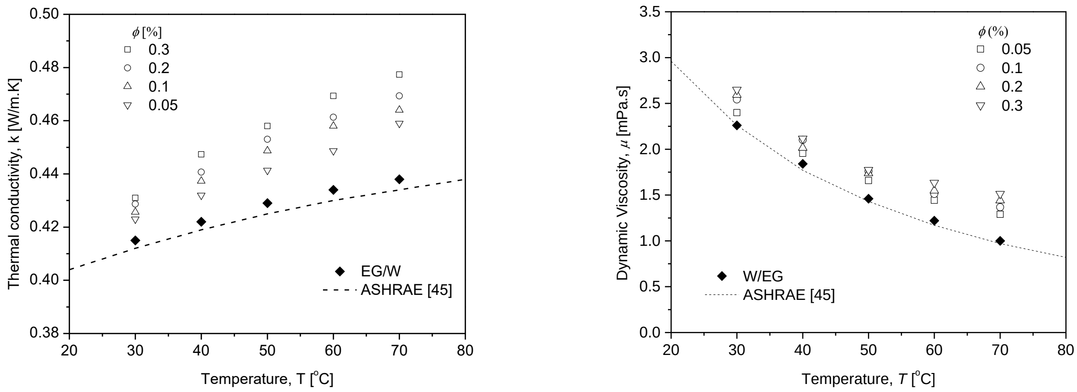
$$P = \left(\frac{W_{nf}}{\rho_{nf}}\right)\Delta P_{nf} \quad (22)$$

3. Result and Discussion

3.1. *Thermal conductivity and dynamic viscosity of tri-hybrid nanofluids*

Figure 2 (a) to 2 (b) shows the thermal conductivity and dynamic viscosity of Al_2O_3-TiO_2-SiO_2 nanofluids for the experimental data of various volume concentrations of 0.05–0.3% and different temperatures of 30–70 °C. As observed in Figure 2 (a), Thermal conductivity of Al_2O_3-TiO_2-SiO_2 nanofluids is increased by increasing the volume and temperature concentration. The tri-hybrid nanofluids curved higher than the base fluid by ASHRAE [45]. The highest increase was found at 70 °C and the volume concentration was 0.3% with 9.6% higher than liquid based. This occurs because particle collisions are more at high temperatures and affect kinetic energy to increase thermal conductivity [31]. Thermal conductivity of Al_2O_3-TiO_2-SiO_2 nanofluids is always higher than the base fluid for all volume concentrations. The same pattern was also observed by previous researchers [30, 36, 46].

Figure 2 (b) demonstrated the variation of viscosity for different concentrations and temperatures. Viscosity of Al_2O_3-TiO_2-SiO_2 nanofluids increases with increasing concentration of volume and decreases with increasing temperature, following the trend of



(a) (b)

Figure 2. Thermal properties of tri-hybrid nanofluids with various temperatures for (a) thermal conductivity and (b) dynamic viscosity [9]

basic fluid and single TiO_2 nanofluid. Esfe et al. [47], highlighting that fluid internal shear stress is greater at high volume concentrations whereas temperature increases weaken inter-molecular interactions. Increased viscosity with respect to particle concentrations is clearly much greater than base fluid at high volume concentrations. The interaction between Al_2O_3-TiO_2-SiO_2 nanoparticles and base fluid (water/EG) also contribute to the greater enhancement as compared to base fluid. The viscosity of nanofluids followed the trend, which decreased with the increase of temperature. This is because the intermolecular interactions between the molecules become weak when the temperature rises.

3.2. *Heat transfer performance of tri-hybrid nanofluids*

Figure 3 (a) to 3 (b) illustrated the heat transfer coefficient and Nusselt number of Al_2O_3-TiO_2-SiO_2 nanofluids at 70 °C. It can be observed that the experimental data for Al_2O_3-TiO_2-SiO_2 nanofluids is in good agreement with the data trend given by Dittus and Boelter [48] 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.

3.3. *Thermal performance of tri-hybrid nanofluids*

Figure 4 (a) to 4 (b) demonstrated the overall heat transfer and NTU of Al_2O_3-TiO_2-SiO_2 nanofluids at 70 °C. It can be observed that the experimental data for Al_2O_3-TiO_2-SiO_2 is in good agreement with the data trend. The overall heat transfer increased with increasing of Reynolds number. The maximum enhancement of were found at volume concentration of 0.3% with 18.3% meanwhile for NTU was found highest at 0.05% volume concentration with 23.8%. The Reynolds

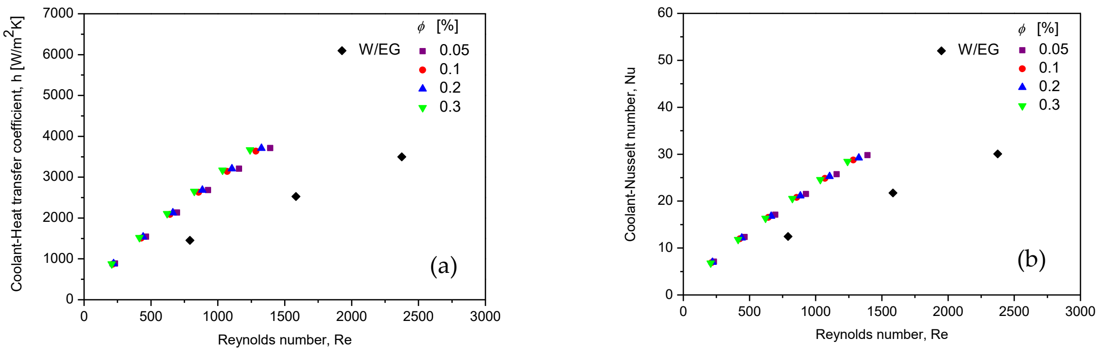
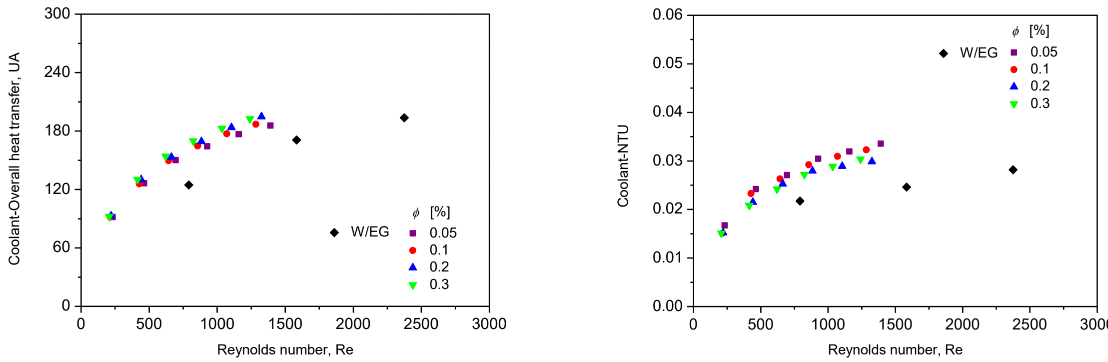


Figure 3. Heat transfer performance of *tri*-hybrid nanofluids at working temperature 70 °C for (a) Heat transfer coefficient; (b) Nusselt number (*Nu*)



(a) (b)

Figure 4. Thermal Performances of *tri*-hybrid nanofluids at working temperature 70 °C for (a) The overall heat transfer; (b) The NTU (Number Thermal Unit)

number was influenced the increasing of the overall heat transfer of the nanofluids. The pattern of the concentration improved with increasing of Reynolds number and positioned higher than the base fluid.

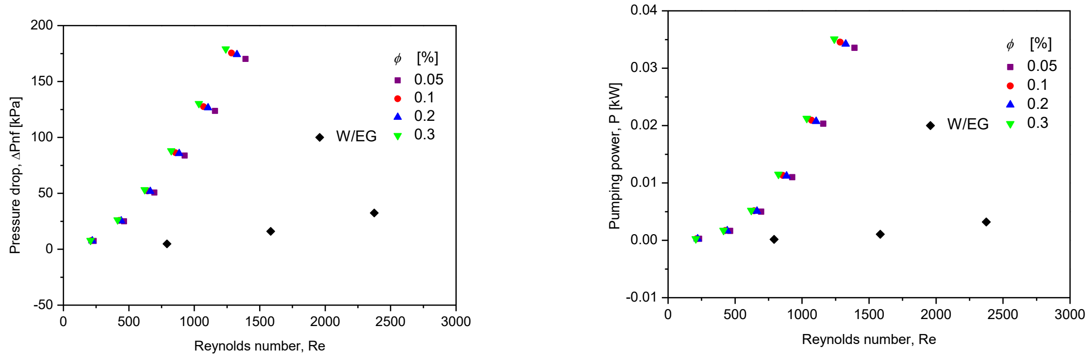
3.4. Pressure drop and pumping power of tri-hybrid nanofluids

Figure 5 (a) and 5 (b) presented pressure drop and pumping power from the Al_2O_3-TiO_2-SiO_2 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. However, all of the concentrations were above the base fluid which is improved from the base fluid.

3.5. Heat transfer coefficient and fin efficiency at air side

Figure 6 demonstrated heat transfer coefficient and fin efficiency of Al_2O_3-TiO_2-SiO_2 nanofluids at temperature 70 °C. The figure shows the heat transfer coefficient of Al_2O_3-TiO_2-SiO_2 nanofluids at temperature 70 °C. The Reynolds number was influenced the increasing of heat transfer coefficient by 23.8% maximum enhancement is found at volume concentration of 0.05%. However, all of the concentrations were lower than base fluid since it has lower concentrations to be compared to the base fluid.

Figure 7 presented the fin efficiency of Al_2O_3-TiO_2-SiO_2 nanofluids at 70 °C. It can be observed that all of the Al_2O_3-TiO_2-SiO_2 nanofluids were above the base fluid since it has lower concentrations to be compared with the base fluid. Maximum enhancement was found at 0.05% volume concentration with 6% compared with the base fluid. Volume of concentration 0.05% is the highest in fin efficiency was due to lower viscosity hence the rate of cooling will be faster.



(a) (b)

Figure 5. (a) Pressure drop of Al_2O_3-TiO_2-SiO_2 nanofluids at working temperature 70 °C; (b) Pumping power of Al_2O_3-TiO_2-SiO_2 nanofluids at working temperature 70 °C

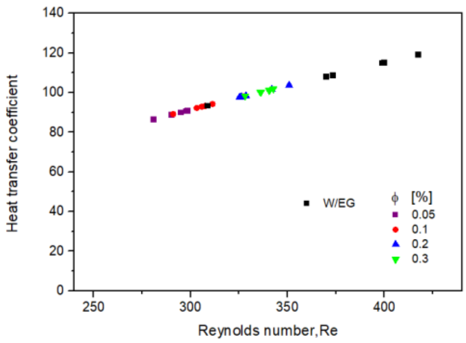


Figure 6. The air heat transfer coefficient with Reynolds number of Al_2O_3-TiO_2-SiO_2 nanofluids at temperature 70 °C

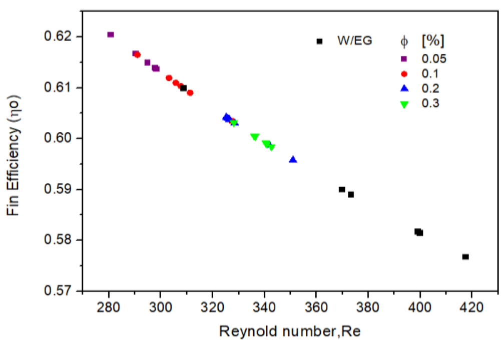


Figure 7. The air fin efficiency with Reynolds number of Al_2O_3-TiO_2-SiO_2 nanofluids at temperature 70 °C

4. Conclusion

In the current study, the thermal performance of Al_2O_3-TiO_2-SiO_2 nanofluids in a water/EG (60:40) mixture has been investigated for volume concentrations up to 0.3% and working temperature of 70 °C. The heat transfer coefficient of Al_2O_3-TiO_2-SiO_2 nanofluids increased with increasing volume concentrations and temperatures. The maximum enhancement of heat transfer coefficient for air side is observed up to 23.8% at 0.05% volume concentration meanwhile for coolant side is observed at 39.7% at 0.3% volume concentration. The overall heat transfer also can be observed to be higher at 0.3% volume concentration when increasing in Reynolds number. 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 are applicable for water/EG (60:40) mixture and Al_2O_3-TiO_2-SiO_2 nanofluids with volume concentrations of 0.05 to 0.3% at 70 °C working temperature.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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The authors declare no competing interest.

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