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Effect Of Nanoparticle Sizes And Concentration On The Al_2O_3 – Water Based Nanofluids Heat Transfer

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Abstract—Experimental works were conducted to investigate the effect of Al_2O_3 sizes and volume concentration on the rate of nanofluids heat transfer in a compact heat exchanger. Two sizes of Al_2O_3 nanoparticle, 40 nm and 100 nm, were mixed with demineralized water at 2%, 6% and 10% volume concentrations. Sodium Lauryl Sulphate (SLS) powder was added to enhance the mixing process and stabilize the dispersion of the nanofluids. A custom-made closed loop test rig were designed, fabricated and tested for these experiments. The test rig was set-up to represent the actual application of the nanofluids in cooling of a compact heat exchanger. Experimental runs were conducted which include the runs for water, 40 nm Al_2O_3-water and 100 nm Al_2O_3-water. The results indicate that Al_2O_3-water gave better heat transfer performance than water alone. Nanofluids with 40 nm- Al_2O_3 gives better heat transfer performance as compared to 100 nm-Al_2O_3 nanofluids. The results of the current work generally indicate that nanofluids have the potential to enhance the heat transfer of a compact heat exchanger if properly designed. This superior performance of the nanofluids would only be produced if smaller diameter of nanoparticles were used (less than 100 nm). No enhancement in heat transfer can be observed by using nanofluids with particle size of 100 nm or at higher volume loading (more than 5%).

Keywords: Compact heat exchanger, Aluminium-oxide, Nanofluids, Radiator, Heat transfer

Introduction

Car radiator, one example of compact heat exchanger, is an important part in automotive cooling system. Fins attached to it enhance heat transfer from the hot coolant to the outside air. The conventional coolant used is water or water mixed with ethylene glycol (EG). Due to the low convective heat transfer on the air side, the radiator is normally placed in front of the car to maximize the cooling effect of the oncoming air. The size and the position of the radiator affect the aerodynamic drag experienced by the car which subsequently compromises the fuel consumption and emission.

Nanofluidsseem to be the potential replacement of conventional coolants in radiator. Nanofluids are dilute suspensions of nanoparticles with at least one of their principal dimensions smaller than 100 nm [1]. These nanoparticles could be aluminum oxide (Al_2O_3), copper (Cu), copper oxide (CuO), gold (Au), silver (Ag), silica nanoparticles and carbon nanotube. There have been considerable research findings highlighting superior heat transfer performance of nanofluid. Yu et al[2] reported that about 15-40% of heat transfer enhancement can be achieved by using various types of nanofluids. With these superior characteristics, the size and weight of an automotive car radiator can be reduced without affecting its heat transfer performance. Singh *et al*[3]have determined that the use of high-thermal conductive nanofluids in radiators can lead to a reduction in the frontal area of the radiator by up to 10%. This reduction in aerodynamic drag can lead to a fuel saving of up to 5%.

The initial promise of nanofluids as advanced heat transfer fluids was based on the increased thermal conductivity of nanoparticle suspensions[4]. It has been shown that nanofluids exhibit much higher thermal conductivities than their base fluids even when the concentration of the suspended nanoparticles is very low. Eastman et al.[5]found that by adding 5% volume fraction of Al_2O_3 (33 nm) nanoparticles in water, the thermal conductivity can be enhanced by 29%. For bigger diameter of Al_2O_3 nanoparticles, such as 80 nm, the enhancement was observed to be about 24% for 5% volume loading [6]. The thermal conductivity of nanofluids increases with an increase in volume fraction of the suspended nanoparticles [7]–[9]. Also comparison with various data by X. Q. Wang and Mujumdar [10] indicates that the thermal conductivity of nanofluids increases with decreasing particles size. The thermal conductivity also increases with an increase in temperature[11].

Unfortunately thermal conductivity is not the only property that determines the efficiency of heat transfer in the system. Convective heat transfer coefficient also plays an important role in evaluating heat transfer capability of an automotive radiator. In the forced flow system (such as in engine cooling by radiator) the coolant is pumped through the radiator, introducing convective heat transfer mechanisms and pumping power penalties.Heris et al [12]investigated convective heat transfer of Al_2O_3/water based nanofluids under laminar flow conditions through annular copper tube. They observed that the heat transfer coefficient increases with the increase in particle volume fraction. The convective heat transfer coefficient increases with increasing flow velocity, Reynolds number and particle concentration [13], [14]. It is also increases with decreasing particles sizes[15].

Majority of the experimental studies on the heat transfer of nanofluids were constrained to the determination of their thermal conductivity, viscosity, convective heat transfer coefficient without considering the performance of the nanofluids under actual application, especially in automotive cooling. Peyghambarzadeh et al [16],conducted heat transfer study in the application of Al_2O_3 nanofluids as coolant for car radiators. They conclude that by adding as much as 1.0% volume of Al_2O_3 to the basefluid (water or EG), the Nusselt number can be increased by up to 40%.

Therefore, most of the published works concluded that nanofluids have superior heat transfer performance based on their thermo physical properties, rather than the actual application. Hence it is the objective of this work to investigate the heat transfer performance of the Al_2O_3nanofluids used a coolant in the car radiator. The effect of particle volume fraction and sizes on the heat transfer were also examined.

Experimental Set-Up

In order to measure the heat transfer performance of the nanofluid in the car radiator, a closed flow loop test rig shown in Fig. 1 has been designed, fabricated, assembled, tested and used. The rig includes a storage tank, a heater, a pump, a flow meter, a cross-flow finned tube heat exchanger (car radiator) and flow lines (stainless-steel tubes). The storage tank is used as the nanofluid storage and holding container during theexperiments. It has the diameter of 75 mm and the height of 150 mm. The tank is fitted with an immersion heater with a power rating of 3 kW, equipped with temperature controller.

The car radiator configuration is louvered fin and flat tubes with an overall dimension of 150 mm x 121 mm x 25 mm and weighs about 270 g. It is made of aluminium. A cooling fan with the size of 120 mm x 120 mm x 25 mm and rotating speed of 1200-2500 RPM was used to cool the radiator in an indirect cross-flow configuration. Type-K thermocouples were used to measure the temperatures at the inlet and the exit of the car radiator, as well as at several locations along the flow lines to ensure steady temperature distribution.

A. Experimental Procedures

The Al_2O_3-water nanofluids were prepared by adding several grams of Al_2O_3 nanoparticles to 800 ml of demineralized water. The amount of nanoparticle added depends on the required volume concentration. Four samples of nanofluids were prepared. Initially the samples were mixed using ultrasonic bath, but due to ineffectiveness of the mixing process, mechanical stirrer was used. However using the stirrer did not provide a long period of stabilized dispersion of the nanoparticles. Hence, surfactant was added to the mixture, about 2% mass fraction of Sodium Lauryl Sulphate powder (SLS). The sample was then mixed using the stirrer for four hours.

i. Heat Transfer of Water.

To provide a basis for comparison, experiments were conducted to evaluate heat transfer performance of water as the coolant in the test rig. 800 ml of water was circulated in the test rig for four hours at the required operating temperature of 40°C. The flow rate for these experiments was set at 1.5 LPM as to emulate laminar flow condition.

ii. Heat transfer for nanofluids.

The Al_2O_3-water nanofluids which have been prepared earlier were pumped into the test rig. It was then heated and circulated under the flowrate of 1.5 LPM (under laminar condition) at the required operating temperature for the duration of four hours. Since there were four samples of nanofluids, four experiments were conducted. For all the experiments, the operating temperature was set at 40°C.

B. Experimental Observation

i. Properties of Nanofluids

The thermophysical properties of the prepared Al_2O_3-water nanofluid are determined at the fluids' bulk mean temperature, T_b by using the correlations widely used in the literature. The

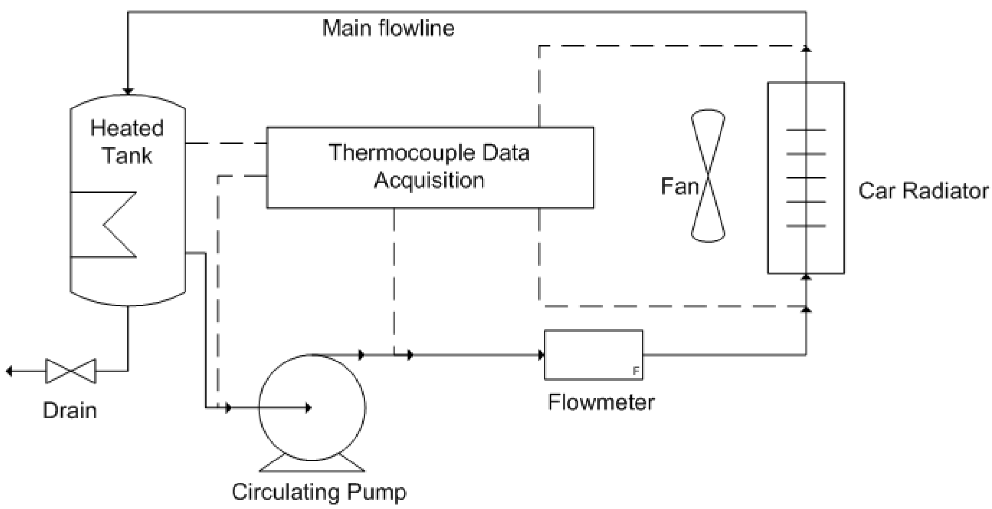

Fig. 1.Schematic diagram of the experimental test rig

density of the nanofluid is determined using Pak and Cho's equation [17].

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

where φ is volume fraction of nanoparticle. Indices of *p*, *bf* and *nf* refers to nanoparticles, base fluid, and nanofluid, respectively. The specific heat of the nanofluid is calculated using Xuan and Roetzel's equation [18].

$$(C_p)_{nf} = \frac{(1-\varphi)(\rho C_p)_{bf} + \varphi(\rho C_p)_p}{\rho_{nf}} \quad (2)$$

Hamilton and Crosser [19] developed one of the basic models for the prediction of thermal conductivity of nanofluids as follows:

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

where n is the empirical shape factor and it is 3 for spherical nanoparticles. The viscosity model used in this work is developed by Nguyen et al [20] by curve-fitting experimental works conducted for CuO-water nanofluids.

$$\mu_{nf} = \mu_{bf}\left(1.475 - 0.319\varphi + 0.051\varphi^2 + 0.009\varphi^3\right) \quad (4)$$

ii. Heat Transfer Coefficient

The heat transfer rate (W) is calculated from

$$Q = \dot{m}C_p(T_{in} - T_{out}) \quad (5)$$

where Q is the rate of heat transfer (W), $\dot{m}$ is the nanofluid mass flowrate (kg/s) and C_p is the specific heat capacity of the nanofluid (J/Kg.K). The heat transfer rate can also be determined from the Newton's Law of Cooling:

$$Q = hA_s(T_b - T_s) \quad (6)$$

By collecting Equation (5) and (6), the heat transfer coefficient for the nanofluid side is:

$$h = \frac{\dot{m}C_p(T_{in} - T_{out})}{A_s(T_b - T_s)} \quad (7)$$

RESULTS AND DISCUSSION

A. Effect of Volume Concentration

The nanofluids are implemented by the addition of Al_2O_3 nanoparticles into DM water at three different nanoparticle concentrations, i.e. 2%, 6% and 10% volume concentration. Fig. 2 depicts the rate of heat transfer of Al_2O_3-water nanofluids at the volume concentration of 2%, 6% and 10%.

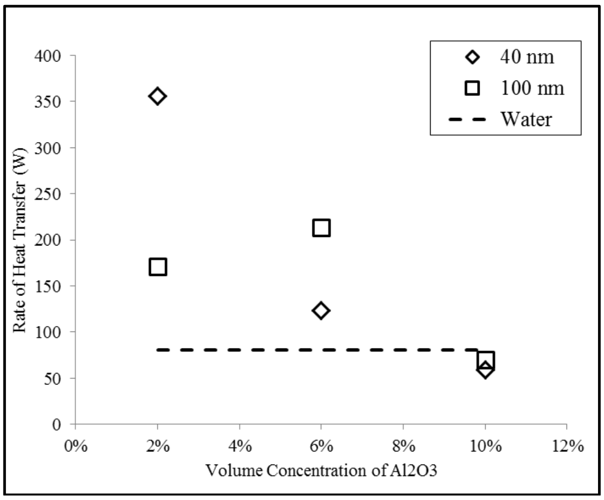

Fig. 2. Effect of Al_2O_3 volume concentration on the rate of heat transfer

Table 1 summarizes the percentage change of heat transfer of the nanofluids as compared to that of water alone.

Table 1. Percentage Change in Nanofluids Heat Transfer as Compared to Water Alone

	Volume Concentration		
Size	2%	6%	10%
40 nm	341.04%	52.36%	-26.70%
100 nm	112.52%	164.43%	-12.72%

By adding 2% volume concentration of 40nm - Al_2O_3 on the base fluid, the heat transfer increases by 314% from that of the base-fluid (water) alone. However, when the volume loading was increases to 6%, the heat transfer decreases although still superior to that of water alone. The heat transfer decreases further when the volume loading increases.

It has been proven that by increasing the concentration of the nanoparticles to the base fluid, even in the slightest amount, would increase the nanofluids thermal conductivity [5], [9], [21]–[24]. Hence, it is expected that the heat transfer should increases when the volume concentration increases. The contradicting results from this work indicates that the expected enhancement in thermal conductivity may not play an important or significant role in the nanofluids heat transfer. Convection heat transfer may have contributed to to contradicting results.

The heat transfer also increases significantly by 112.5% for nanoluids containing 100 nm Al_2O_3 at the same volume loading of 2% as compared to water. It increases further when the loading increased to 6%. However at 10% volume loading, the heat transfer reduces below that of water alone. This finding indicate an optimum value of volume concentration, which occurs approximately at 6% volume concentration.

It can also be observed that for both nanoparticles sizes, the heat transfer is lower than that for water alone. Hence it can be said that nanofluids would not provide better heat transfer when the volume loading exceed 6%.

The effect of the nanoparticle volume concentration on the convection heat transfer coefficient is shown in Fig. 3.At low volume loading of 6% and less, the convection heat transfer coefficient increases in the range of 53.6% - 344% from that of water alone. The highest convection coefficient is attained by 40 nm-Al_2O_3 nanofluids at 2% volume loading. Above 6%, i.e. 10% volume loading, the convection heat transfer coefficient decreases from that for water alone, further strengthening the finding that nanofluids with 10% volume loading does not perform better than water.

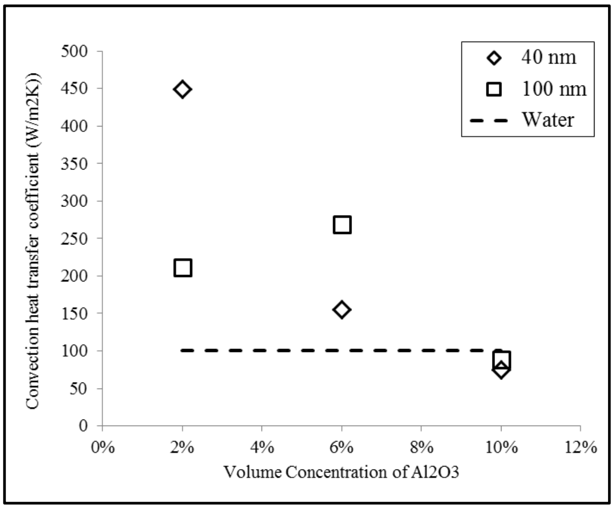

Fig.3. Effect of Al_2O_3volume concentration on the convection heat transfer coefficient

B. Effect of Size

Fig. 4 shows that at low nanoparticle loading of 2%, the heat transfer for 40 nm-Al_2O_3 is greater than that of 100 nm- Al_2O_3. In other words, the rate of heat transfer increases for decreasing sizes. At 2% volume concentration, the heat transfer increases from 171 W to 355.7 W, i.e. more than 100% increment, when the particle size reduces from 100 nm to 40 nm. This is attributed by an increase in the effective thermal conductivity of the nanofluids as the particle sizes reduces. The enhancement in the effective thermal conductivity has been explained by many researchers as a consequence of the Brownian motion [24]-[26].

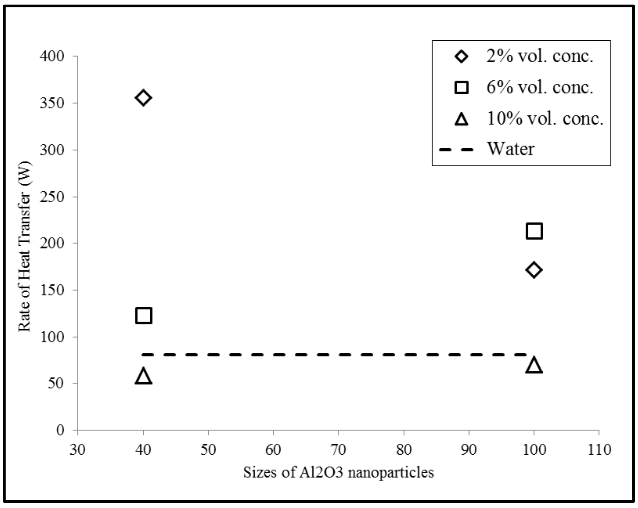

Fig.4. Effect of Al_2O_3sizes on the rate of heat transfer.

However conflicting trend was observed at higher nanoparticle volume concentration. Above 6% volume concentration, the rate of heat transfer increases as the sizes increases. In Fig. 4, it can be clearly seen that there is no enhancement of heat transfer for nanofluids with 10% volume concentration as compared to that of water alone.

The effect of the nanoparticle sizes on the convection heat transfer coefficient is shown in Fig.5. At low loading of Al_2O_3, the coefficient decreases from 449 W/m^2K to 211 W/m^2K as the size reduces, indicating superior performance of 40 nm-Al_2O_3nanoluids at 2% volume concentration. At higher volume loading of 6%, the convection heat transfer coefficient increases from 155 W/m^2K to 269 W/m^2K with sizes. No significant enhancement in convection heat transfer coefficient is observed for 10% volume loading.

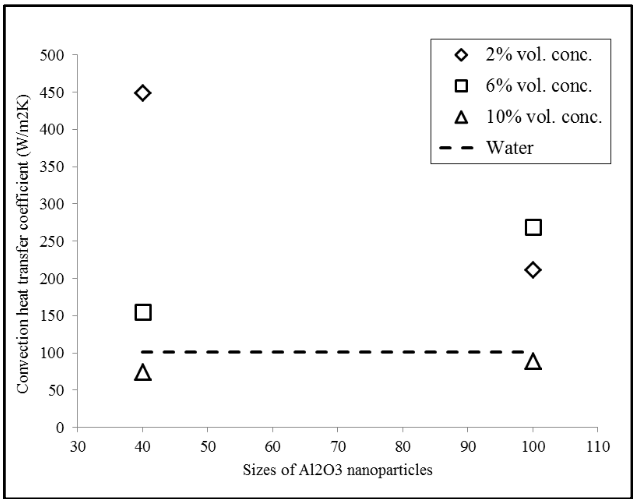

Fig. 5. Effect of Al_2O_3volume concentration on the convection heat transfer coefficient

Conclusions

The results of the current work indicate that nanofluids has the potential to enhance the heat transfer of a compact heat exchanger if properly designed. The following conclusions were derived from this work:

- Addition of small amount of Al_2O_3 nanoparticles into DM water as the base fluid would increase the rate of heat transfer by at least 112%.
- As the volume loading increases, heat transfer decreases. This indicates that thermal conductivity may not be the only factor in determining the performance of the nanofluds.
- At low nanoparticle loading of 2%, the heat transfer for 40 nm-Al_2O_3 is greater than that of 100 nm- Al_2O_3. In other words, the rate of heat transfer increases for decreasing sizes.
- No significant enhancement in heat transfer can be observed by using nanofluids with particle size of 100 nm or at higher volume loading (6% and above).

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