Heat Transfer Enhancement of Automobile Radiator with TiO_2/Water Nanofluid

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Abstract

In this paper, forced convective heat transfer in a water based nanofluid will experimentally be compared to that of pure water in an automobile radiator. Five different concentrations of nanofluids in the range of 0.1 - 1 vol. % will be prepared by the addition of TiO_2 nanoparticles into the water. The test liquid flows through the radiator consisted of 34 vertical tubes with elliptical cross section and air makes a cross flow inside the tube bank with constant speed. Liquid flow rate will be changed in the range of 2 - 5 l/min. Additionally the effect of fluid inlet temperature to the radiator on heat transfer coefficient will also be analyzed by varying the temperature in the range of 37 - 49 ^{0}C. Results will demonstrate that increasing the fluid circulating rate can improve the heat transfer performance while the fluid inlet temperature to the radiator has trivial effects. Meanwhile it was observed from investigators, application of nanofluid with low concentrations can enhance heat transfer efficiency up to 45% in comparison with pure water.

Keywords— *Nanofluid, Heat transfer coefficient, TiO_2, Radiator, Cooling performance*

1. Introduction

A reduction in energy consumption is possible by improving the performance of heat exchange systems and introducing various heat transfer enhancement techniques. Since the middle of the 1950s, some efforts have been done on the variation in geometry of heat exchanger apparatus using different fin types or various tube inserts or rough surface and the like [1-7]. Some of the published investigations have focused on electric or magnetic field application or vibration techniques [8-11]. Even though an improvement in energy efficiency is possible from the topological and configuration points of view, much more is needed from the perspective of the heat transfer fluid. Further enhancement in heat transfer is always in demand, as the operational speed of these devices depends on the cooling rate. New technology and advanced fluids with greater potential to improve the flow and thermal characteristics are two options to enhance the heat transfer rate and the present article deals with the latter option.

Conventional fluids, such as refrigerants, water, engine oil, ethylene glycol, etc. have poor heat transfer performance and therefore high compactness and effectiveness of heat transfer systems are necessary to achieve the required heat transfer. Among the efforts for enhancement of heat transfer the application of additives to liquids is more noticeable. Recent advances in nanotechnology have allowed development of a new category of fluids termed nanofluids. Such fluids are liquid suspensions containing particles that are significantly smaller than 100 nm, and have a bulk solids thermal conductivity higher than the base liquids [12]. Nanofluids are formed by suspending metallic or non-metallic oxide nanoparticles in traditional heat transfer fluids. These so called nanofluids display good thermal properties compared with fluids conventionally used for heat transfer and fluids containing particles on the micro meter scale [13]. Nanofluids are the new window which was opened recently and it was confirmed by several authors that these working fluid can enhance heat transfer performance.

Pak and Cho [14] presented an experimental investigation of the convective turbulent heat transfer characteristics of nanofluids (Al_2O_3-water) with 1-3 vol. %. The Nusselt number for the nanofluids increases with the increase of volume concentration and Reynolds number.

Wen and Ding [12] assessed the convective heat transfer of nanofluids in the entrance region under laminar flow conditions. Aqueous based nanofluids containing Al_2O_3 nanoparticles (27-56 nm; 0.6-1.6 vol. %) with sodium dodecyl benzene sulfonate (SDBS) as the dispersant, were tested under a constant heat flux boundary condition. For nanofluids containing 1.6 vol. %, the local heat transfer coefficient in the entrance region was found to be 41%higher than that of the base fluid at the same flow rate. Heris et al. [15] examined and proved the enhancement of in-tube laminar flow heat transfer of nanofluids (water-Al_2O_3) in a constant wall temperature boundary condition. In other work, Heris et al. [16] presented an investigation of the laminar flow convective heat transfer of Al_2O_3-water under constant wall temperature with0.22.5 vol. % of nanoparticle for Reynolds number varying between700 and 2050. The Nusselt number for the nanofluid was found to be greater than that of the base fluid; and the heat transfer coefficient increased with an increase in particle concentration. The ratio of the measured heat transfer coefficients increases with the Peclet number as well as nanoparticle concentrations.

Lai et al. [17] studied the flow behaviour of nanofluids (Al_2O_3-water; 20 nm) in a millimeter sized stainless steel test tube, subjected to constant wall heat flux and a low Reynolds number (Re< 270). The maximum Nusselt number enhancement of the nanofluid of 8% at the concentration of 1 vol. % was recorded. Jung et al. [18] conducted convective heat transfer experiments for a nanofluid (Al_2O_3-water) in a rectangular micro channel under laminar flow conditions. The convective heat transfer coefficient increased by more than 32% for 1.8 vol. % nanoparticle in the base fluids. The Nusselt number increased with an increasing Reynolds number in the laminar flow regime (5< Re< 300) and a new convective heat transfer correlation for nanofluids in micro channels was also proposed.

Sharma et al. [19] implemented 12.5 vol.% Al_2O_3 in water in a horizontal tube geometry and concluded that at Pe number of 3500 and 6000 up to 41% promotion in heat transfer coefficient compared to pure water may be occurred. Ho et al. [20] conducted an experiment for cooling in horizontal tube in laminar flow of Al_2O_3-water at 1 and 2 vol. % concentration and concluded the interesting enhancement of 51% in heat transfer coefficient. Nguyenet al. [21] performed their experiments in the radiator type heat exchanger and at 6.8 vol. % Al_2O_3 in water obtained 40% increase in heat transfer coefficient.

He et al. [22] investigated the heat transfer and flow behaviour of TiO_2-distilled water nanofluids were flowing in an upward direction through a vertical pipe in both the laminar and transition flow regimes under a constant heat flux boundary condition. The results indicated that the convective heat transfer coefficient increased with an increase in nanoparticle concentration at a given Reynolds number and particle size. They also found that the pressure drop of the nanofluids was approximately the same as that of the base fluid.

Duangthongsuk and Wongwises [23,24] examined the convective heat transfer and pressure drop of TiO_2-water nanofluid flowing in a horizontal double tube counter flow heat exchanger under turbulent flow conditions experimentally. The TiO_2 nanoparticles with diameters of 21 nm dispersed in water with volume concentrations of 0.2–2%. Their results showed that the heat transfer coefficient of nanofluid was higher than that of the base liquid and increased with increasing the Reynolds number and particle concentrations. Moreover, their results illustrated that the heat transfer coefficient of the nanofluids at a volume concentration of 2.0% was lower than that of base fluid.

In this paper, forced convection heat transfer coefficients are reported for pure water and water/TiO_2 nanopowder mixtures under fully turbulent conditions. The test section is made up with a typical automobile radiator, and the effects of the operating conditions on its heat transfer performance are analyzed.

2. Nanofluids Preparation

Preparation of nanoparticles suspension is the first step in applying nanofluid for heat transfer experiments. In this work the TiO_2-water nanofluid is prepared by a two-step method. The TiO_2 nanoparticles with an average size of 15 nm have been provided by NANOSHEL. As the provided nanoparticles had a hydrophobic surface, they agglomerated and precipitated when dispersed in water in the absence of a dispersant/ surfactant. Moreover, addition of any agent may change the fluid properties. Thus, the decision is made to functionalize the TiO_2 nanoparticles by a chemical treatment. The TiO_2 nanoparticles were mixed with 1, 1, 1,3,3,3, hexamethyldisilazane (C6H19NSi2) in a mass fraction ratio of 2:1. The resulting mixture was sonicated at 30 °C for 1 h using ultrasonic vibration at sound frequency of 40 kHz. This process permitted to place the hydrophilic ammonium groups on TiO_2 nanoparticles surface. Then, the soaked nanoparticles were dried with a rotary evaporation apparatus. Eventually, specific quantities of these functionalized nanoparticles are mixed with distilled water as the base fluid to make nanofluids in particular volume fractions. The suspensions were subjected to ultrasonic vibration at 400W and 24 kHz for 3–5 h to obtain uniform suspensions and break down the large agglomerations.

Fig. 1 shows the field emission scanning electron microscope (FESEM) image of the nanoparticles after dispersing in water. The prepared nanofluids in the present study remained stable for several days without any observable sedimentation.

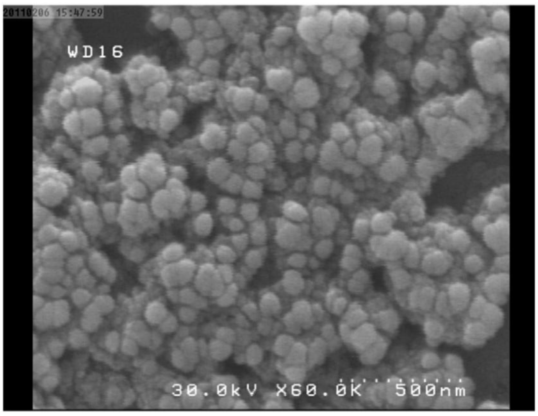

Fig. 1 FESEM image of nanoparticles after dispersion.

3. Nanofluids properties

Before the study of the convective heat transfer performance of the nanofluids the properties of nanofluid must be known accurately. By assuming that the nanoparticles are well dispersed in the fluid, the concentration of nanoparticles may be considered uniform throughout the tube. Although this assumption may be not true in real systems because of some physical phenomena such as particle migration, it can be a useful tool to evaluate the physical properties of a nanofluid.

The density of nanofluid is calculated by the mixing theory as:

$$\rho = \emptyset \rho_P + (1-\emptyset)\rho_{bf} \tag{1}$$

The specific heat capacity of nanofluid can be calculated based on the thermal equilibrium model as follows

$$C = \frac{\emptyset \rho_P c_P + (1-\emptyset)\rho_{bf} c_{bf}}{\rho} \tag{2}$$

The effective dynamic viscosity of nanofluids can be calculated using Einstein's equation [25] for a viscous fluid containing a dilute suspension ($\varphi \leqslant 2\%$) of small, rigid, spherical particles [26]. As very dilute suspensions were used in this work the Einstein equation was used to estimate the viscosity of nanofluids. Wen and Ding [12] also used the same equation for calculating the viscosity.

$$\mu = \mu_{bf}\,(1 + 2.5\emptyset) \tag{3}$$

For calculating the effective thermal conductivity of nanofluids the Yu and Choi [27] formula has been used.

$$k = \left[\frac{k_P + 2k_{bf} + 2(k_P - k_{bf})\,(1+\beta)^3 \emptyset}{k_P + 2k_{bf} - (k_P - k_{bf})\,(1+\beta)^3 \emptyset}\right] k_{bf} \tag{4}$$

β is the ratio of the nanolayer thickness to the original particle radius and was set at 0.1 in this study to calculate the effective thermal conductivity of nanofluids [27].

It should be noted that these transport properties are functions of temperature. As a consequence, the properties were calculated by using the mean fluid temperature between the inlet and outlet.

4. Calculation of heat transfer coefficient

To obtain heat transfer coefficient and corresponding Nusselt number, the following procedure has been performed. According to Newton's cooling law:

$$Q = hA\Delta T = hA(T_b - T_w) \tag{5}$$

Heat transfer rate can be calculated as follows:

$$Q = mC_p\Delta T = mC_p(T_{in} - T_{out}) \tag{6}$$

Regarding the equality of Q in the above equations:

$$Nu = \frac{h_{exp} d_{hy}}{k} = \frac{mC_p(T_{in} - T_{out})}{A(T_b - T_w)} \tag{7}$$

In Eq. (7), Nu is average Nusselt number for the whole radiator, m is mass flow rate which is the product of density and volume flow rate of fluid, C_p is fluid specific heat capacity, A is peripheral area of radiator tubes, T_{in} and T_{out} are inlet and outlet temperatures, T_b is bulk temperature which was assumed to be the average values of inlet and outlet temperature of the fluid moving through the radiator, and T_w is tube wall temperature which is the mean value by two surface thermocouples. In this equation, k is fluid thermal conductivity and d_{hy} is hydraulic diameter of the tube. It should also be mentioned that all the physical properties were calculated at fluid bulk temperature.

Conclusion

In this review article, experimental heat transfer coefficients in the automobile radiator have been reviewed with two distinct working liquids: pure water and water based nanofluid (small amount of TiO_2 nanoparticle in water) at different concentrations and temperatures and the following conclusions were made.

1. The presence of TiO_2 nanoparticle in water can enhance the heat transfer rate of the automobile radiator. The degree of the heat transfer enhancement depends on the amount of nanoparticles added to pure water.

2. Increasing the flow rate of working fluid (or equally Re) enhances the heat transfer coefficient for both pure water and nanofluid considerably while the variation of fluid inlet temperature to the radiator (in the range tested) slightly changes the heat transfer performance.

3. It seems that the increase in the effective thermal conductivity (of about 3% in this study) and the variations of the other physical properties are not responsible for the large heat transfer enhancement. Brownian motion of nanoparticles may be one of the factors in the enhancement of heat transfer. Although there are recent advances in the study of heat transfer with nanofluids, more experimental results and theoretical understanding of the mechanisms of the particle movements are needed to explain heat transfer behavior of nanofluids.

Nomenclature

c: specific heat, J/kg K
k: thermal conductivity, W/m K
Nu: Nusselt number
Pr: Prandtl number
Re: Reynolds number
T: Temperature, K
A: peripheral area (m^2)
C_p: specific heat (J/kg K)
d_{hy}: hydraulic diameter (m)¼ (4S/P)
h: heat transfer coefficient (W/m2 K)
m: mass flow rate (kg/s)
Q: heat transfer rate (W)

Greek letters

ρ: density (kg/m^3)
µ: viscosity (kg/m s)
Φ: volume fraction

Subscripts

b: bulk
exp.: experimental
in: input
nf: nanofluid
out: output
p: particle
w: wall

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