HEAT TRANSFER ENHANCEMENT OF CAR RADIATOR USING AQUA BASED MAGNESIUM OXIDE NANOFLUIDS

by

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The focus of this research paper is on the application of water based MgO nanofluids for thermal management of a car radiator. Nanofluids of different volumetric concentrations (i. e. 0.06%, 0.09%, and 0.12%) were prepared and then experimentally tested for their heat transfer performance in a car radiator. All concentrations showed enhancement in heat transfer compared to the pure base fluid. A peak heat transfer enhancement of 31% was obtained at 0.12% volumetric concentration of MgO in basefluid. The fluid flow rate was kept in a range of 8-16 liter per minute. Lower flow rates resulted in greater heat transfer rates as compared to heat transfer rates at higher flow rates for the same volumetric concentration. Heat transfer rates were found weakly dependent on the inlet fluid temperature. An increase of 8 °C in inlet temperature showed only a 6% increase in heat transfer rate.

Key words: *nanofluid, MgO, car radiator, heat transfer enhancement*

Introduction

It has been a keen interest of researchers for quite a long time to enhance the heat transfer in devices used in industries and in our daily life to increase their performance and efficiency. In past different techniques like free and forced convection, and extended surfaces were used for transferring heat at a higher rate. In the recent era, researchers are interested to find new ways to increase the heat transfer and as a result, today, we have come across a term known as nanofluids. Nanofluids are consisted of nanoparticles which are ranging of 10 nm to 100 nm, suspended in the base fluid.

Radiators have wide applications ranging from industrial machines to automobiles. Automobile manufacturers are in tough competition to improve automobiles efficiency and performance, they cannot overlook the heat sink (radiator) used in automobiles. It is an important part of an automobile which is used to keep the engine cool. An approach to achieve this cooling is to use nanofluids in car radiator to enhance heat transfer. A significant importance is given to the use of nanofluid in heat exchangers of different types, such as fin heat sinks [1], shell and tube heat exchangers [2], and double-tube heat exchangers [3]. However, a few studies have been reported about use of nanofluids in car radiators. Yu *et al.* [4] presented a review and summarized that 15%-40% enhancement in heat transfer can be achieved by using different kinds of nanofluids.

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Lee *et al*. [5] by using transient hot wire method, found the thermal conductivity of Al_2O_3-EG, Al_2O_3-water, CuO-EG, and CuO-water. It was observed that the thermal conductivity vary with the shape and size of the particles along with the thermal properties of the nanoparticles and base fluid. Xuan and Li. [6] reported that the thermal conductivity of nanofluids is higher in comparison with pure water. Their experimental investigation consisted of water based nanofluids (containing Cu nanoparticles) passing through a straight tube under constant heat flux. Results showed a negligibly small effect over power consumption caused by nanofluid friction factor at less concentration. Chandrasekar *et al*. [7] found that by increasing volume concentration the thermal conductivity increased. Das *et al*. [8] reported that nanofluid thermal conductivity increased by increasing temperature and could not be predicted by thermal conductivity effective model. They found that the conduction of heat will be more if the particles in the nanofluid are more because it results in a greater surface area for the transfer of heat.

Peyghambarzadeh *et al.* [9] used Al_2O_3/water nanofluids in a car radiator and recorded a heat transfer enhancement of 45% at about 1% volumetric concentration. Peyghambarzadeh *et al*. [10] used Al_2O_3/mixture of ethylene glycol (EG) and water in a car radiator. They recorded a 40% enhancement in heat transfer as compared to the base fluids under same conditions. Duangthongsuk and Wongwises [11] used TiO_2/water nanofluid and performed an experiment by flowing it in a regime of turbulent flow to study the pressure drop and heat transfer performance. They found that the pressure drop in nanofluids was slightly greater compared to the base fluid and by increasing volumetric concentration its value increased. Esfe et al. [12] performed experiments and found that an addition of nanoparticles of MgO in less than 1% volumetric concentration in base fluid caused a heat transfer enhancement. It was found that the pressure drop in the nanofluid was higher as compared to base fluid, but without having any significant increase in power consumption. Xie *et al.* [13] used ZnO, MgO, Al_2O_3, and TiO_2 nanoparticles in a mixture of 45 vol. % of EG and 55 vol. % of distilled water acting as a base fluid. They found that the heat transfer coefficient could be enhanced by the above stated nanofluids during a laminar flow in a copper tube of a circular cross-section having a constant wall temperature. It was observed that Al_2O_3, MgO, and ZnO showed greater enhancement in heat transfer coefficient. The MgO showed the peak value of enhancement of about 252% at about Re = 1000. Leong *et al*. [14] used Cu/EG nanofluids in a car radiator to check the performance of Cu/EG nanofluids. It was found that by only 2% vol. of Cu/EG nanofluids, an overall coefficient of heat transfer of about 164 W/m^2K was recorded as compare to the 142 W/m^2 K shown by base fluid. Ali *et al*. [15] experimentally investigated the performance of ZnO water based nanofluids in a radiator. The best heat transfer enhancement up to 46% was found compared to base fluid at 0.2% volumetric concentration.

Nanofluids give their best results only if they are prepared well. Nanofluids can be prepared by two methods: single and two step methods.

In single step method, nanoparticles agglomeration is reduced and fluid stability is increased by avoiding the processes like drying, storage, transportation, and dispersion of the nanoparticles, Li *et al.* [16]. This is done by a process that combines the formation of nanoparticles and preparation of nanofluids. Hence, both these stages occur simultaneously. Zhu *et al*. [17] prepared agglomeration free and stable Cu nanofluids using a single step method. They used EG containing $NaH_2PO_2{\cdot}H_2O$ to reduce $CuSO_2{\cdot}5H_2O$ under the irradiation of a microwave to prepare Cu nanofluids. Lo *et al.* [18, 19] prepared nanofluids of CuO by using single step method. The resulting nanofluid proved to avoid aggregation of particles, resulted in uniform distribution of nanoparticles and well regulated size of nanoparticles of CuO which were suspended in deionized water. Singh and Raykar [20] used single step method with microwave assistance to prepare silver nanofluid that was stable for almost one month.

Most commonly used method for the preparation of nanofluids is the two step method. In this method nanomaterials such as nanoparticles or nanotubes, *etc*., are first prepared by using physical or chemical method in the form of a dry powder. In the second step, this dry powder is dispersed in a base fluid. As the process of preparation of nanoparticles and nanofluids are separated, hence agglomeration is more evident in this method. Dispersion of nanoparticles in the base fluid can be improved and agglomeration can be minimized by using techniques like surfactant addition, ultrasonic agitation or high shear mixing, *etc*. Murshed *et al*. [21] prepared TiO_2/water nanofluid by using two step method. Xuan and Li [22, 23] and Li and Xuan [24] used two step method for preparing Cu/oil and Cu/water nanofluids. Techniques of ultrasonic agitation and addition of surfactants in the fluid were used to avoid aggregation of the nanoparticles. Choi *et al*. [25] used two step method to prepare the suspension of carbon nanotube.

As the nanofluids are suspensions, thus nanoparticles suspended in the base fluids aggregate and ultimately settle down with the passage of time. This does not only affect stability of the nanofluids but also reduces its thermal conductivity. To evaluate the stability of a nanofluid, four different methods are used: (1) sedimentation method, (2) centrifugal method, (3) spectral absorbency analysis, and (4) zeta potential method [20, 26-28].

Present study is focused on the performance analysis of MgO/water nanofluids by using in an automotive car radiator. Experimental conditions were tried to keep as close as possible to the conditions of working automotive car radiator. Furthermore, nanofluids of different volumetric concentrations were used and experimentation was done at different liquid flow rates to have thorough understanding of thermal performance enhancement of nanofluids in automotive car radiator.

Experimental set-up and methodology

Figure 1(a) shows a schematic diagram of experimental set-up. The experimental set-up consists of a data acquisition system (for acquiring data), a centrifugal pump (to provide flow), a flowmeter (to measure flow rate), a fan (to provide air), a heat exchanger (car radiator), a tank (reservoir for nanofluid), a heater (to heat fluid), thermocouples (to measure temperature at different points), and flow lines (to provide passage for the fluid and to complete the loop). Flow rate of the fluid is controlled with the help of two high precision gate valves. The maximum output of the pump is 25 lpm.

Fluid is taken from the tank (dimensions L×W×H, 533.4 mm × 152.4 mm × 685.8 mm) by the pump. Fluid then passes through the regulating valves and flowmeter (Omega FL-45100,

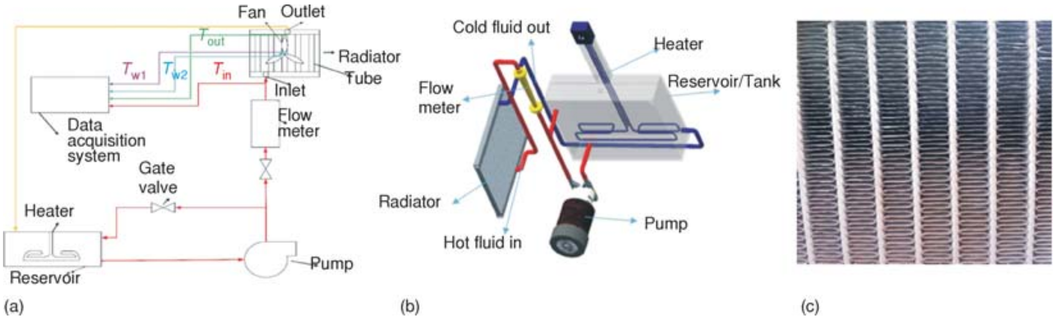

Figure 1. (a) Process flow diagram, (b) 3D-schematic diagrem, (c) louvered finned tubes

Table 1. Radiator dimensions (mm)

Length ×Width ×Height	25.13×1.26×350
Peripheral area of tube	184793
Hydraulic diameter	2.410574
Perimeter	52.798
Total tube area	381.821

temperature limit of 1000 °C, + 2% accuracy) and then to the heat exchanger (car radiator). A bypass line is also provided at the outlet of the pump to return the excessive fluid back to the tank. A heater (Omega- CH-OTS-604/240 V, 6 KW) is used to heat the fluid in the tank. The heater has a built in temperature controller with an accuracy of ±1 °C. The inlet temperature of the heater is controlled with the help of heater temperature controller. The heat exchanger is a conventional aluminum car radiator and its dimensions are given in tab. 1. To get the inlet, outlet, and wall temperatures of the radiator, K-type thermocouples (Omega 5TC series, ±0.1 °C) are used. The wall temperature is taken from the middle tube of radiator.

Data acquisition system (Agilent 34972-A) is used to acquire data from thermocouples and to display it. This system can display temperature up to six decimal places. All the equipments are manufacturer calibrated with certifications. Figure 1(b) shows a 3-D schematic of experimental set-up.

The car radiator used was made up of aluminum. It was consisted of 32 vertical aluminum tubes (only 12 tubes were kept open). The gap between the tubes is filled with thin perpendicular louvered fins as shown in the fig. 1(c). Air was forced to flow through the fins of the radiator using a conventional forced draft fan (700-800 rpm).

Table 2. Properties of MgO nanoparticles used

Purity [%]	99
Approximate size [nm]	20
Color	White
Morphology	Nearly spherical
True density [gcm^{-3}]	3.58

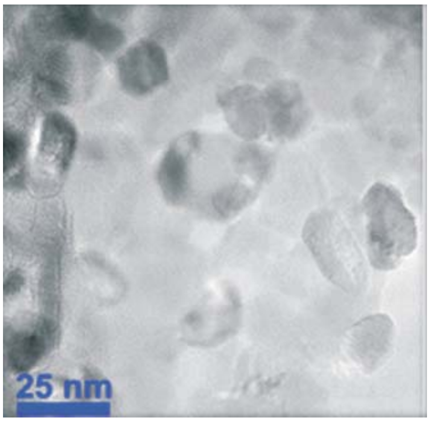

Figure 2. The TEM of nanoparticles (Nanostructured and Amorphous Materials, Inc.)

The experimentation is performed at constant flow rates of 8, 10, 12, 14, and 16 lpm for a specified interval of time and at a particular inlet temperature of 60 °C. A test was carried out to determine the effect of inlet temperature on concentration at three different temperatures of 56 °C, 60 °C, and 64 °C.

The nanoscale elements of MgO are purchased from Nanostructured and Amorphous Materials, Inc. (NanoAmor) having a size of 20 nm (see fig. 2). Table 2 gives the properties of the MgO nanoparticles used in this investigation. The solubility of MgO in water is increased by lowering the pH of the distilled water and making it more acidic. The solubility of MgO particles increased, by lowering the pH of water. At a pH of 2.2, the solution became transparent from whitish and remained stable for observation period of one week (fig. 3).

Nanofluids preparation

Two step method is used to prepare the nanofluids. Particles are first dissolved in distilled water and the pH was maintained at almost 2. Then a constant stirring for three hours is performed using magnetic stirrer. To prevent any chances of agglomeration, two hours of sonication is further performed in an ultrasonic cleaner. This process provided a stable and homogeneous aqua-based MgO nanofluid. As shown in fig. 3, these nanofluids were stable even after one week. A good repeatability in heat transfer results was also achieved (it will be discussed later).

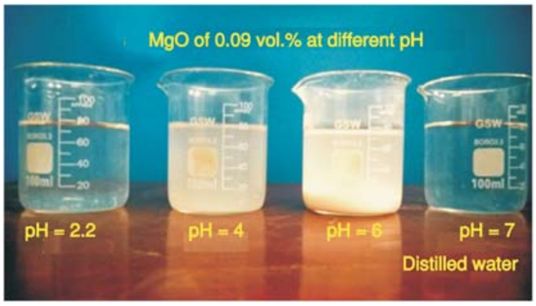

Figure 3. Samples of nanofluids after one week

Data reduction

All nanofluids thermo-physical properties are highly temperature dependent and are calculated at the fluid bulk temperature which is the average of the inlet and outlet tube temperature.

Density of nanofluids was calculated by the formula given by Pak and Cho [29], whereas for specific heat of nanofluids, Xuan and Roetzel [30] correlation was used which assumes thermal equilibrium between the particles and base fluid:

$$\rho_{\text{nf}} = \varphi\rho_{\text{p}} + (1-\varphi)\rho_{\text{bf}} \tag{1}$$

$$Cp_{\text{nf}} = \frac{\varphi(\rho Cp)_{\text{p}} + (1-\varphi)(\rho Cp)_{\text{bf}}}{\rho_{\text{nf}}} \tag{2}$$

where the subscripts nf, bf and p refer to nanofluid, basefluid, and particle, respectively. φ is the volumetric concentration of nanoparticles in basefluid *i. e.* water.

Esfe *et al.* [31] proposed a well-accepted model which was used in computing the viscosity of nanofluids:

$$\mu_{\text{nf}} = \mu_{\text{bf}}(1 + 11.61\varphi + 109\varphi^2) \tag{3}$$

where μ_{bf} and μ_{nf} are the viscosity of basefluid and nanofluid, respectively.

Heat transfer rate, can be calculated from the formula:

$$Q = \dot{m}Cp(T_{\text{in}} - T_{\text{out}}) \tag{4}$$

where Q is the heat transfer rate, $\dot{m}$ – the mass flow rate, Cp – the specific heat and T_{in} and T_{out} are the inlet and outlet temperature respectively.

Heat transfer coefficient can be determined experimentally by the relation:

$$h = \frac{\dot{m}Cp(T_{\text{in}} - T_{\text{out}})}{A(T - T_{\text{w}})} \tag{5}$$

where h is the heat transfer coefficient, A – the total peripheral area of the tubes, T – the average temperature of the inlet and outlet temperature known as bulk temperature, and T_{w} – the wall temperature measured at the center point of the middle tube of radiator.

Peripheral area is given by the formula:

$$A = 2(lh^\circ + lw) \tag{6}$$

where l is the length, w – the width, and h° – the height of flattened tube of car radiator.

Nusselt number can be calculated by the relation:

$$\mathrm{Nu} = \frac{hD}{k} \tag{7}$$

where h is the convective heat transfer coefficient, D – the hydraulic diameter of the tubes, and k – the thermal conductivity of the fluid.

Hydraulic diameter of tubes can be calculated by the formula:

$$D = \frac{4A'}{P} \tag{8}$$

where A' is the tube surface area and P – the perimeter of the tubes.

Uncertainty analysis

Experimental uncertainties were estimated using the method of Kline and McClintock [32]. This method incorporates the estimated uncertainties in the experimental measurements (*e. g.* coolant flow rate, coolant inlet, and outlet temperatures) into the final parameters of interests (*e. g.* heat transfer rate, calculated Reynolds number, *etc.*). Using the measured uncertainties of the above mentioned parameters, the maximum calculated uncertainties in heat transfer rate were never found to be more than 10%. For pure water, fluid mass flow rate and fluid temperature difference were found to be equally significant for calculated uncertainty. However, for nanofluids only fluid mass flow rate participated significantly in calculated uncertainty. The maximum uncertainty in calculated Reynolds number was found to be 2.7% for all cases due to the mass flow rate uncertainty.

Results and discussions

Validation of experimental results

Experimental set-up accuracy has been verified by testing it on distilled water (tab. 3). For this purpose, Dittius and Boelter [33] correlation was used. Dittius-Boelter correlation gave Nusselt number of the distilled water in turbulent flow range. This was then compared with experimental values taken at different flow rates.

Theoretical Nusselt number can be calculated from empirical correlation for turbulent flow as given by Dittus and Boelter [33]:

$$\mathrm{Nu} = 0.0236\mathrm{Re}^{0.8}\mathrm{Pr}^{0.3} \tag{9}$$

where Nu is the Nusselt number, Re – the Reynolds number and Pr – the Prandtl number given by the correlation:

$$\mathrm{Pr} = \frac{\mu Cp}{k} \tag{10}$$

where μ is the viscosity, of the fluid.

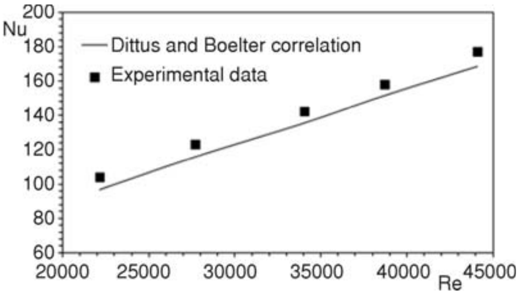

Figure 4. Comparison of experimental results with the empirical equation of Dittus and Boelter [33]

Figure 4 shows the comparison between the experimental Nusselt number and that calculated by the correlation [33]. It can be seen that the error between the theoretical and experimental Nusselt number is less than 8% for all readings suggesting the high accuracy of experimental measurements.

Repeatability of data has been checked by repeating heat transfer readings after one week. Figure 5 shows the repeatability of data of 0.09 vol.% of MgO with the same operating conditions. It can be seen clearly that readings show repeatability within 3%.

Table 3. Physical properties of distilled water at 55 °C

Physical properties	Water
ρ [kgm^{-3}]	985.919
μ [kgm-s]	0.00050092
k [Wm^{-1}°C^{-1}]	0.6469
Cp [Jkg^{-1}K^{-1}]	4181.268

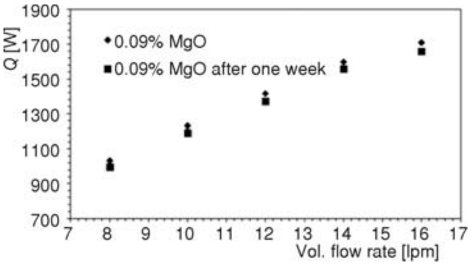

Figure 5. Data repeatability-heat transfer rate

Heat transfer rate of nanofluids

Figure 6 compares the rate of heat transfer of nanofluids prepared at different volumetric concentrations with distilled water as a function of volume flow rate. Readings were taken at flow rates of 8, 10, 12, 14, and 16 lpm for each volumetric concentration of 0.06%, 0.09%, and 0.12%, respectively. It can be seen clearly that for a specific volumetric concentration, heat transfer rate is increased by increasing the flow rate.

Water when used as a coolant has a heat transfer rate of 859 W and 1476 W at 8 lpm and 16 lpm, respectively. At 0.06% volumetric concentration of MgO, about 15% increase in heat transfer rate was recorded at every flow rate compared to water. At 0.09% volume concentration, the heat transfer enhancement range was 15.8% to 20.2%, while at 0.12% volume concentration, the maximum observed heat transfer enhancement was 31% at 8 lpm compared to distilled water.

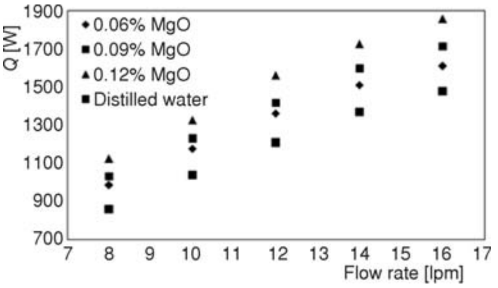

Figure 6. Heat transfer rate of distilled water and MgO nanofluid at different concentrations

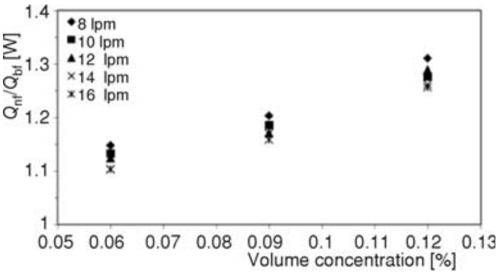

Figure 7. Heat transfer ratio at different volume concentration

Figure 7 represents the ratio of the heat transfer rate of nanofluid to base fluid while varying the fluid volumetric concentration. It can be seen that the addition of nanoparticles enhances the heat transfer ratio *i.c.* $Q_{\mathrm{nf}}/Q_{\mathrm{bf}}$ having a maximum value at 0.12 vol. %. The graph indicates that the low flow rates yields more heat transfer enhancement. At the same volume concentration, the heat transfer ratio at 8 lpm is 4.3% greater than that of 16 lpm.

Xuan and Li [6] developed the following correlation for estimating the heat transfer performance of nanofluids in the turbulent flow regime, which was used for comparison of the experimental Nusselt number with the calculated one:

$$\mathrm{Nu}_{\mathrm{nf}} = 0.0059\left[1 + 7.6286\varphi^{0.6886}\left(\frac{\mathrm{Re}_{\mathrm{nf}}\,\mathrm{Pr}_{\mathrm{nf}}\,d_{\mathrm{p}}}{D}\right)^{0.001}\right]\mathrm{Re}_{\mathrm{nf}}^{0.9238}\,\mathrm{Pr}_{\mathrm{nf}}^{0.4} \tag{11}$$

Thermal conductivity of nanofluids is calculated using the equation given by Hamilton and Crosser [34]:

$$k_{\mathrm{nf}} = \frac{k_{\mathrm{p}} + (z-1)k_{\mathrm{bf}} - \varphi(z-1)(k_{\mathrm{bf}} - k_{\mathrm{p}})}{k_{\mathrm{p}} + (z-1)k_{\mathrm{bf}} - \varphi(k_{\mathrm{bf}} - k_{\mathrm{p}})} k_{\mathrm{bf}} \tag{12}$$

where k is the thermal conductivity and z – the empirical shape factor. As nanoparticles used in this investigation are nearly spherical in shape (see tab. 2), value of z is taken as 3.

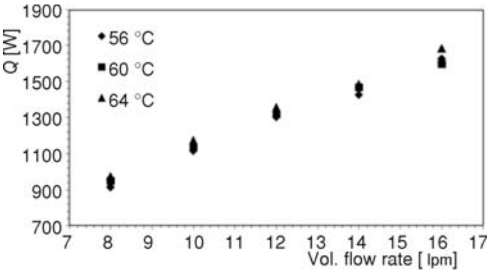

Figure 8. Comparison of experimental and theoretical Nusselt number

Figure 8 compares the theoretical and experimental Nusselt number as a function of Reynolds number at various volumetric concentration. It can be seen clearly from figure that although the experimental data correlates quite well with the calculated data as the predicted error for MgO nanofluid at all tested volumetric concentration lies under 14.8%. However, this correlation does not predict Nusselt number of nanofluids accurately. The figure shows that Xuan and Li [6] correlation almost under predicts the Nusselt number of MgO nanofluids. The similar behavior is also reported by other researchers who previously worked on nanofluids [11].

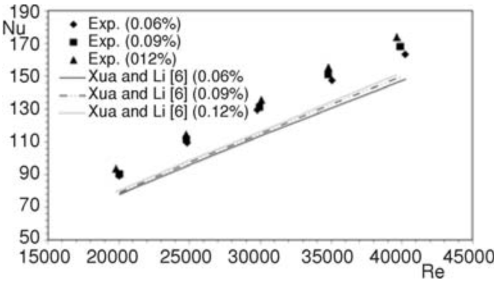

Figure 9. Heat transfer rates of 0.06% vol. MgO nanofluid at three different temperatures

Effect of inlet temperature on heat transfer rate of nanofluids

Figure 9 shows heat transfer rate of 0.06% volume concentration of MgO nanofluid at inlet temperatures of 56 °C, 60 °C, and 64 °C. It can be seen clearly from the figure that increasing the inlet temperature of the fluid slightly increases the heat transfer rate. By increasing the inlet temperature of the fluid from 56 °C to 64 °C, the maximum heat transfer rate was increased to 6.7%. Peyghambarzadeh *et al.* [10] reported the same effect of inlet temperature and proposed that the liquid radiation in the internal walls of tube plays an important role in the heat transfer enhancement.

Conclusions

In this paper, the convective heat transfer enhancement of automobile car radiator has been experimentally studied by using MgO water based nanofluids at different flow rates and at various volumetric concentrations to study their behavior. The following major conclusions are obtained.

- Addition of MgO nanoparticles in water considerably enhances the heat transfer rates as compared to pure water.
- The maximum observed heat transfer enhancement of MgO nanofluid was 1.31, translating 31% increase in heat transfer rate at 0.12% volumetric concentration and at a flow rate of 8 lpm.

- The heat transfer rate has shown an increasing trend by increasing the volumetric concentration up to a certain tested volumetric concentration *i. e.* 0.12%.
- Heat transfer rates are weakly dependent on the inlet fluid temperature. An increase in inlet temperature from 56 °C to 64 °C, only showed a maximum 6% increase in heat transfer rate.
- Lower flow rates resulted in greater heat transfer rates as compared to higher flow rates for the same volumetric concentration.
- The MgO/water nanofluids showed good repeatability when experimentally tested after one week, however, there is a need to produce more stable nanofluids for long terms in order to be used in engineering applications.

Nomenclature

A – peripheral area of tubes, [m^2]
A' – tube surface area, [m^2]
Cp – specific heat, [Jkg^{-1}K^{-1}]
D – hydraulic diameter of tube, [m]
d – nanoparticle diameter, [m]
h – heat transfer coefficient, [Wm^{-2}K^{-1}]
$h°$ – height of the tube of radiator, [m]
k – thermal conductivity, [Wm^{-1}K^{-1}]
l – length of tube of radiator, [m]
$\dot{m}$ – mass flow rate, [kgs^{-1}]
Nu – Nusselt number
P – perimeter of a flattened tube of radiator, [m]
Pr – Prandtl number
Q – heat transfer rate, [W]
Re – Reynolds number
T – temperature, [K]
V – velocity of the flow, [ms^{-1}]
w – width of car radiator, [m]

Greek symbols

α – thermal diffusivity, [m^{-2}s^{-1}]
μ – viscosity, [kgm^{-1}s^{-1}]
ρ – density, [kgm^{-3}]
φ – nanoparticle volumetric fraction, [%]

Subscripts

b – bulk
bf – base fluid
in – inlet
nf – nanofluid
out – outlet
p – nanoparticle
w – wall

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