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# Experimental study of heat transfer enhancement in automobile radiator using $Al_2O_3$/water–ethylene glycol nanofluid coolants

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## ABSTRACT

An experimental study on heat transfer enhancement in an automobile radiator using $Al_2O_3$/water–ethylene glycol (EG) nanofluids is carried out. Heat transfer enhancement studies can help in the design of lighter and more compact radiators for the same given load, which in turn can improve the fuel economy of the automobile. A closed loop experimental setup is designed using a commercial automobile radiator for the study. The effect of adding EG to water on the overall heat conductance (UA) is studied using two mixtures of water–EG proportions, 90:10 and 80:20 (by volume). They showed a reduction in UA by 20% and 25% respectively. Experiments have also been done using $Al_2O_3$/water–EG nanofluids. The nanofluid was prepared using an 80:20 mixture and 0.1% (vol.) of $Al_2O_3$ nanoparticles. The addition of nanoparticles enhanced the heat transfer performance by 37 %. All the experiments have been conducted at a constant coolant flow rate and coolant inlet temperatures varying from 40 $^oC$ to 70 $^oC$. The results showed that the heat transfer performance of the radiator reduced with the addition of EG and increased with the addition of nanoparticles to the water–EG mixture.

***Keywords***: Radiator; heat transfer; engine coolant; ethylene glycol; nanofluids, alumina,

## INTRODUCTION

Weight reduction has been a major focus for automobile manufacturers in recent years to improve the fuel economy of the vehicle and consequently the running cost. A 5 % reduction in weight of an automobile would increase its fuel economy by about 2 % [1]. The engine and its subsystem constitute about 15 % of the total weight of the automobile and thus any weight reduction brought into this system can contribute considerably to improved fuel economy [2, 3]. The engine cooling system is one of the prospective engine subsystems for weight reduction. The radiator in this subsystem, usually a plate fin or tube fin compact heat exchanger, is used to cool the hot engine coolant before it reenters the engine. Many studies have been done to enhance the heat transfer in such heat exchangers and in the engine cooling systems. Some of them include the use of helically twisted tapes in tubes [4], [5], [6], nanotube surface coating [7], electric field and nanofluids as coolants by a method called the electro-hydrodynamic enhancement method (EHD) [8]. Such heat transfer enhancement studies can help in the design of smaller radiators for the same given power, which in turn can reduce the weight.

With advances in nanotechnology, the use of nanofluids as coolants in the heat exchanger has become popular [9-12]. Huminic [13] present a detailed review of literature on the use of nanofluids in heat exchangers [11, 14, 15]. Das et al. [16] described nanofluids as liquid suspensions containing particles of nanometer sizes. The particles used include chemically stable metals (e.g., copper, gold, silver), metal oxides (e.g., alumina, bismuth oxide, silica, titania, zirconia), several allotropes of carbon (e.g., diamond, single-walled and multi-walled carbon nanotubes, fullerenes) [17-20]. These particles have thermal conductivities that are orders of magnitude higher than the base liquid, and sizes significantly smaller than 100 nm [21]. Due to the use of high conductivity particles, they greatly enhance the heat transfer characteristics of the original fluid. Peyghambarzadeh et al. [22] experimentally studied the heat transfer characteristics of $Al_2O_3$/water nanofluid in an automobile radiator. They conducted experiments with volume concentrations of $Al_2O_3$ ranging from 0.1 to 1.0 % (vol.) and coolant flow rates ranging from 2 to 5 litres per minute. It was reported that with the application of nanofluid with low concentrations, the heat transfer increased by 45 % as against pure water. It was concluded that the enhancement was not only due to the high thermal conductivity of the nanoparticles but also due to their Brownian motion. Peyghambarzadeh et al. [23] experimentally analysed the heat transfer enhancement with water–ethylene glycol (EG) and water–EG mixtures-based $Al_2O_3$ nanofluids. Their experiments were performed for *Re* 9000–23000 for water-based nanofluids and 1200–2500 for ethylene-glycol-based nanofluids. The ranges of the various parameters were: coolant inlet temperature, $35^o$ to $50^o$C for water-based nanofluids and 45 $^o$C to 60 $^o$C for ethylene-glycol-based nanofluid, the flow rate, 2–6 litres per minute, and nanoparticle concentration, 0 to 1% (vol.). The nanofluid was prepared without addition of dispersant and stabilizer, and a 1% (vol.) of nanoparticles heat transfer improvement of 40% was achieved as against pure fluids, and higher *Nu* was observed with water-based nanofluids.

Naraki et al. [24] experimentally studied the heat transfer enhancement in a car radiator using CuO/water nanofluids. The nanofluids in all the experiments were stabilized by varying the pH of the solution using sodium dodecyl sulfonate as surfactant. The experiments were conducted for coolant flow rates varying from 0.2 to 0.5 $m^3$/hr. Three volume fractions of nanoparticles were used in the experiments: 0, 0.15 and 0.4 % (vol.). It was observed that the overall heat transfer coefficient increased by 8 % with 0.4 % (vol.) of CuO and it increased with the increase in coolant flow rate. Conversely, the overall heat transfer coefficient decreased with increase of the nanofluid inlet temperature. Peyghambarzadeh et al. [25] experimentally studied the overall heat transfer coefficient of dilute nanofluids in car radiators using copper oxide (CuO) and iron oxide ($Fe_2O_3$) nanoparticles. Nanofluids were prepared by adding nanoparticles to water at three concentrations, 0.15, 0.4, and 0.65 % (vol.) using dispersants to control the pH of the solution. In these experiments, the liquid side flow rate was varied in the range 0.05 to 0.11 lps per tube and the inlet temperature was varied between 50 and 80 $^o$C. The use of nanofluids showed a greater overall heat transfer coefficient in comparison with water, with 0.65 % (vol.) of nanoparticles, and an enhancement of 9% was obtained with $Fe_2O_3$ and 7 % with CuO.

Hussain et al. [26] experimented with $TiO_2$ and $SiO_2$ nanopowders suspended in pure water. The test setup included a car radiator, and the effects on heat transfer enhancement under the operating conditions were analysed under laminar flow conditions. The volume flow rate, inlet temperature and nanofluid volume concentration were in the range of 2–8 lpm, 60–80 °C and 1–2 % respectively. The results showed that the Nusselt number increased with the volume flow rate and slightly increased with the inlet temperature and nanofluid volume concentration. Hussain et al. [27, 28] studied experimentally and numerically the friction factor and forced convection heat transfer of

$SiO_2$ nanoparticles dispersed in water as a base fluid in a car radiator. Four different concentrations of nanofluids in the range of 1–2.5 vol% were used. The flow rate changed in the range of 2–8 lpm to yield Reynolds numbers in the range of 500–1750. The results showed that the friction factor decreases with increase in the flow rate and increases with increasing volume concentration. Furthermore, the inlet temperature to the radiator had an insignificant effect on the friction factor. Also, the application of $SiO_2$ nanofluid with low concentrations can enhance the heat transfer rate up to 50 % compared with pure water. Based on the literature survey, the following conclusions have been drawn: (i) the nanofluids used are mostly based on water, with very few studies reporting the use of nanofluids based on a water–EG mixture, and in the work reported the mixture had 5 %, 10 % and 20 % (vol.) EG; [29] of the few nanoparticles used, $Al_2O_3$ showed promise. To the best of the author's knowledge, experiments reported with $Al_2O_3$/water–EG have a maximum EG proportion of 20 % (vol.), with studies done only up to a maximum temperature of 60 $^oC$. In actual engine operating conditions, the coolant enters the radiator, regulated by a thermostat, only when its temperature is high (of the order of 75 $^oC$ to 90 $^oC$). The current work focuses on studying the effect of adding EG on the heat transfer performance of the water and $Al_2O_3$/water–EG nanofluids. The objective is to study the effect of adding EG to distilled water on its heat transfer performance in an automobile radiator by quantifying the overall heat conductance (UA), Fujii et al. [29] to study the heat transfer performance of $Al_2O_3$/water–EG nanofluids in automobile radiators up to a maximum temperature of 70 $^oC$.

## METHODS AND MATERIALS

The effect of EG addition is studied using two proportions of water–EG, i.e., 90:10 and 80:20 (by volume). For experiments with $Al_2O_3$/water–EG nanofluids, 80:20 water–EG mixture and 0.1% (vol.) of $Al_2O_3$ are used. The study is carried out with a constant flow rate of coolant and at different coolant temperatures (at the radiator inlet) varying from 40 $^oC$ to 70 $^oC$. The rate of flow of the coolant was measured manually using a litre jar and a stop watch. The time taken to fill one litre was noted down and thus the flow rate was obtained. The procedure was repeated 5 times and the average flow rate was taken. The schematic of the setup used for the experiments is shown in Figure 1.

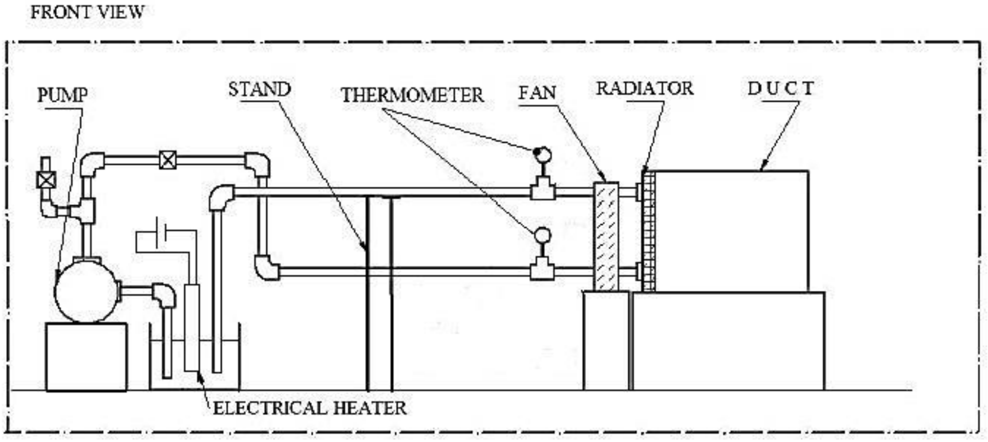

Figure 1. Schematic of experimental setup.

The setup is a closed loop system and the coolant line consists of a storage tank, an electrical heater, a pump, and a radiator. The components are connected using pipes of 1" diameter. The storage tank has a capacity of 90 liters. The coolant is heated in the storage tank using two 1 kW electrical immersion heaters and it maintains coolant temperatures between 40 °C and 70 °C. A 0.2 hp centrifugal pump with a rated flow rate of 40 litres per minute and a rated head of 15 m drives the coolant through the loop. The radiator is a commercial aluminium plate fin type automobile radiator of size 517 mm × 380 mm × 24 mm. The radiator is cooled by forced convection using an electrical fan. The experiments are carried out with a constant flow rate of 0.135 kg/s. Thermocouples are used to measure the air and coolant temperatures. These are measured using a digital thermometer with an accuracy of ±1 °C. As the heating of air is not uniform across the surface of the radiator at the exit, measurements are made at 17 points. These points are located across the vertical and horizontal centre line as shown in Figure 2. The average value of the temperatures measured at these points is taken for the analysis.

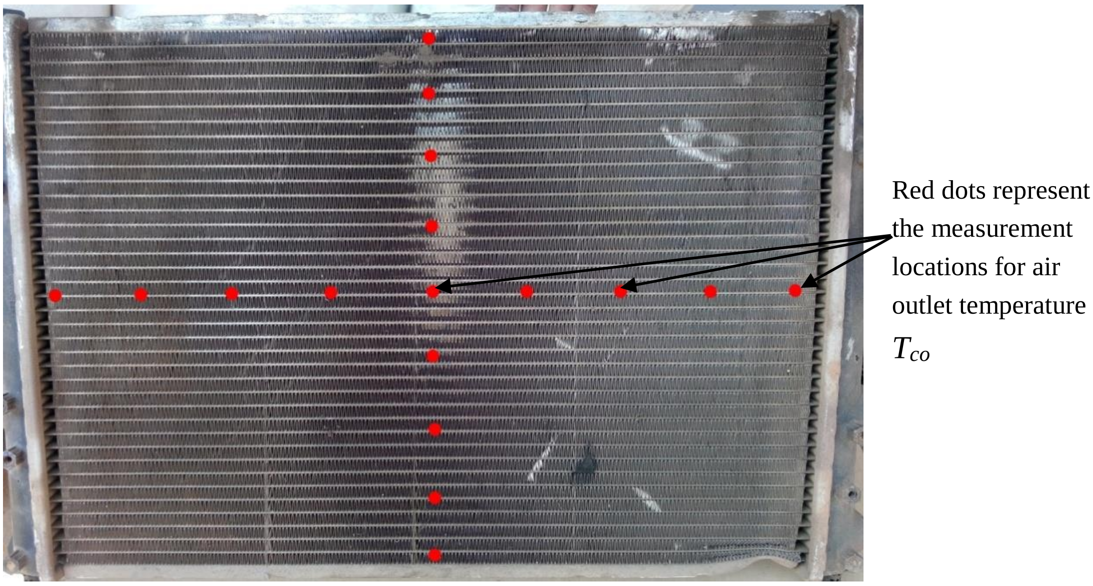

Figure 2. Measurement points for air temperature at outlet.

The nanofluid is prepared by adding 20 nm gamma-$Al_2O_3$ nanoparticles to water–EG mixture and stirring it for an hour using a mechanical stirrer. The water used for the experiments is distilled water and no surfactant is added to the solution for the preparation of the nanofluids. Two proportions of water–EG mixture are used in the experiments to study the effect of EG, i.e., 90:10, and 80:20. A constant volume fraction of 0.1% of nanoparticles is used in all the experiments. The properties of the water, water–EG mixtures and nanofluids used in the experiments are given in Table 1 and all the properties of the coolant have been considered at a mean temperature of 55°C.

The overall heat conductance (UA) is computed by the standard $\varepsilon$-$N_{tu}$ (effectiveness-number of transfer units) method. It is computed according to Eq. (1).

$$UA = N_{tu} \times C_{\min} \tag{1}$$

where $C_{min}$ is the minimum of the heat capacities of the hot (coolant) $C_h$ and cold fluids (air) $C_c$.

$$C_c = \dot{m}_c c_{pc} ; C_h = \dot{m}_h c_{ph} \tag{2}$$

Table 1. Properties of coolant.

| Fluid | Vol. fraction of $Al_2O_3$ | ρ | $c_P$ | K | μ ($\times 10^{04}$) | *Pr* |
|---|---|---|---|---|---|---|
| | (%) | kg/m$^3$ | J/kg-K | W/m-K | N.s/m$^2$ | |
| Water | 0 | 980.2 | 4184.0 | 0.557 | 4.30 | 3.226 |
| 90:10 water–EG | 0 | 993.8 | 4129.6 | 0.529 | 5.26 | 3.223 |
| 80:20 water–EG | 0 | 1006.5 | 4033.4 | 0.502 | 6.47 | 3.218 |
| $Al_2O_3$/water | 0.1 | 980.2 | 4171.5 | 0.558 | 4.31 | 5.187 |
| $Al_2O_3$/80:20 water–EG | 0.1 | 1006.5 | 4021.8 | 0.503 | 6.49 | 6.634 |

As the mass flow rate of the coolant is measured, $C_h$ can be calculated. The value of $C_c$ is obtained from the thermodynamic energy balance assuming no heat loss from the radiator.

$$Q = C_h (T_{hi} - T_{ho}) = C_c (T_{co} - T_{ci}) \tag{3}$$

The number of transfer units $N_{tu}$is obtained from Equation (4) as given by [30]:

$$N_{tu} = -\ln \frac{[1 + \ln(1 - \varepsilon C_R)]}{C_R} \tag{4}$$

where $C_R$ is the heat capacity ratio ($C_{min}/C_{max}$) and the effectiveness is obtained by Equation (5):

$$\varepsilon = \frac{Q}{C_{\min}(T_{hi} - T_{ci})} \tag{5}$$

The experiments have been done with distilled water to verify the analysis methodology. The consistency in the air mass flow rates over different coolant inlet temperatures validated the analysis methodology and the assumptions made.

## RESULTS AND DISCUSSION

### Experiments with Water–EG Mixtures

Ethylene glycol is an anti-freeze additive that is used as an automotive engine coolant to reduce its freezing point. To quantify its effect on the heat transfer performance of the coolant, experiments have been done with two proportions of EG, i.e., 10% and 20%. The UA of the radiator has been obtained for different temperatures of the coolant between 40°C and 70°C. The variation of UA against $T_{hi}$ for water and two mixtures of water–EG is shown in Figure 3. It can be seen that the UA values obtained with water are noticeably higher than those with water–EG mixtures, which is due to the decrease in the thermal conductivity of the fluid. The effect of the volume fraction of EG on the water–EG performance becomes less significant with increase in $T_{hi}$. Based on the average values of UA over the temperature range, it can be seen that there is a reduction of 20% and 25% with the 90:10 and 80:20 mixtures respectively. Thus is due to the decrease in the *Pr* number of the coolant, as seen in Table 1. Lower *Pr* of the coolant reduces the heat transfer coefficient on the coolant side and thus the UA.

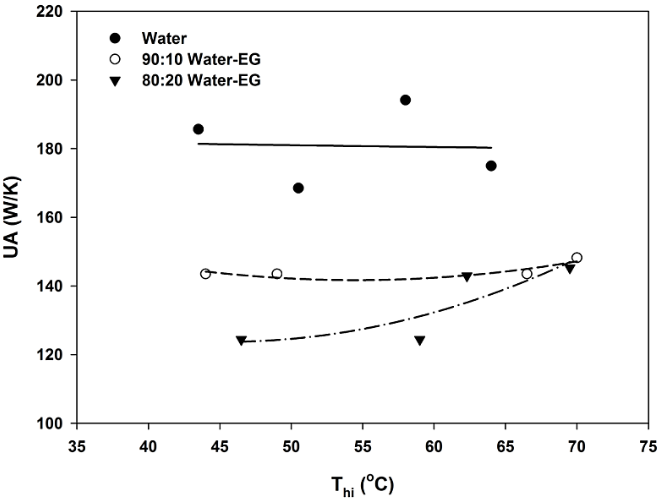

Figure 3. Effect of EG on heat transfer performance of water.

## Experiments with Water–EG Mixtures Nanofluids

Experiments were conducted with nanofluids prepared with the 80:20 water–EG mixture and 0.1% of $Al_2O_3$, varying the coolant temperatures between 40°C and 70°C. The variation of UA for water, 80:20 water–EG mixture and the nanofluids is as shown in Figure 4. It can be seen that the addition of nanoparticles improves the overall conductance. The addition of 0.1% of nanoparticles increases the UA value obtained when using 80:20 water–EG mixtures by 37%. From Table 1, it can be seen that there is a significant increase in *Pr* with the addition of nanoparticles. There are increases of *Pr* by 61% and 106% respectively for water and 80:20 water–EG coolant with the addition of nanoparticles.

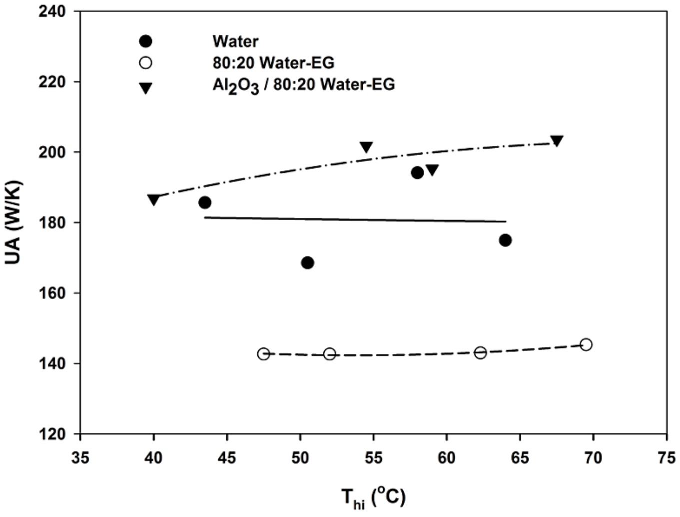

Figure 4. Effect of nanofluids on heat transfer performance.

## CONCLUSIONS

Experiments have been conducted to study the heat transfer characteristics of water–EG mixtures and nanofluids based on $Al_2O_3$/water–EG mixtures for inlet temperatures of the coolant varying between 40°C and 70°C. The following conclusions have been made.

(i) A decline in the heat transfer performance of the radiator with the addition of EG to the coolant has been observed. Based on the average values of UA over the temperature range, reductions of 20% and 25% have been observed with the 90:10 and 80:20 mixtures respectively. There is a tradeoff between the antifreeze property and the heat transfer performance of EG.

(ii) The addition of nanoparticles enhances the heat transfer performance of the coolant. Nanofluid with 0.1% of $Al_2O_3$ in the 80:20 water–EG mixture showed an improvement of 37%. This implies that for the same temperature change there will be an increase in heat transfer by 37%. The enhancement is greater with higher temperatures.

(iii) The significant increase in the *Pr* of the coolant with the addition of nanoparticles results in the increase of UA. With the addition of 0.1% of nanoparticles, the *Pr* of the water and 80:20 water–EG increased by 61% and 106% respectively.

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