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Heat Transfer and Pressure Drop of Al2O3-Ethylene Glycol-water Nanofluid as the Coolant in an Automotive Radiator

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A B S T R A C T

In this experimental study, heat transfer and pressure drop, ΔP, of a coolant nanofluid, obtained by adding alumina nanoparticles to Ethylene Glycol-water mixture (60:40 by mass), in a Automotive radiator have been investigated. For this purpose, an experimental setup has been designed and constructed. The experiments have been performed for base fluid and nanofluid with different volume fractions of 0.003, 0.006, 0.009 and 0.012 and under laminar regime with various coolant flow rates of 9, 11 and 13 lit/min and two air velocities of 3.75 and 2.85 m/s. The thermophysical properties have been calculated using the recently presented temperature dependent models. According to the results, the heat transfer and ΔP increase with increasing the coolant flow and nanoparticles volume fraction. Increasing the air velocity causes enhancement of heat transfer. Although Nusselt number decreases when nanofluid is utilized, it enhances as the nanoparticles volume fraction increases. The performance evaluation using nanofluid in the automotive radiator shows remarkable enhancement in radiator thermal efficiency. However, the ratio of heat transfer rate to the needed pumping power (Merit parameter) decreases.

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1. Introduction

The heat transfer limitations of common working fluids in thermal equipment have led to introduce the "nanofluids" over the past two decades. Nanofluids have many applications in industries such as transportation, electronics cooling, space and defense, and biomedical industry. Nanofluid coolants also have potential application in major process industries, such as materials, chemical, food and drink, oil and gas, paper and printing, and textiles [1].

Water or mixture of water and Ethylene Glycol (EG) are fluids used in the automotive cooling system. These fluids have low thermal conductivity compared to metals and even metal oxides. By using the nanofluids instead of the conventional fluids, heat transfer rate can be increased and hence, smaller dimensions for the cooling system as well as less fluid flow rate can be achieved. Also, more powerful engines could be designed for different climatic conditions.

To the best of our knowledge, Singh et al. [2] were among the first investigators to conduct a study on automotive radiator working with several nanofluids. They determined that use of the nanofluids in radiators can lead to a reduction in the frontal area of the radiator up to 10% and the subsequent reduction in aerodynamic drag can lead to a fuel savings up to 5%. The application of nanofluid also contributed to reduction of friction, wear and parasitic losses, and subsequently leading to more than 6% fuel saving. On the other hand, they observed no erosion using the coolants made of pure fluids, but there was erosion observed with the nanofluids.

A three-dimensional laminar flow and heat transfer with two different nanofluids, Al2O3 and CuO, in an EG-water mixture (60:40 by mass) circulating through the flat tubes of an automobile radiator were numerically studied by Vajjha et al. [3]. They modeled the nanofluids as the single phase fluids. The important novelty of their study was use of new correlations for viscosity and thermal conductivity of nanofluids as a function of temperature. According to their results, at Reynolds number of 2000, the percentage increase in the average heat transfer coefficient over the base fluid for 10% Al2O3 nanofluid was 94% and for 6% CuO nanofluid was 89%. Their simulation showed that the average heat transfer coefficient also increases with the Reynolds number and its influence was stronger than . Also, they reported the average skin friction coefficient for 6% CuO nanofluid in the fully developed region was about 2.75 times greater than that of the base fluid at a constant inlet velocity. For the same amount of heat transfer, the pumping power requirement was 82% lower for Al2O3 nanofluid of 10% volume fraction and 77% lower for CuO nanofluid of 6% volume fraction when compared to the base fluid.

Sheikhzadeh and Fakhari [4] studied the application of Al2O3-EG-water nanofluid in an automobile cooling system for various conditions numerically. They used the temperature dependent correlations to evaluate thermophysical properties for both the nanofluid and the base fluid. They compared their results with the predictions of several Nu correlations existing in the literatures for the nanofluid under laminar flow. They reported that the Nu correlation given by Li and Xuan [5] showed the best agreement with their experimental results.

Peyghambarzadeh et al. [6] studied experimentally forced convective heat transfer of Al2O3-water nanofluid in an automobile radiator under turbulent flow. Their experimental results showed that increasing the fluid circulating rate can improve the heat transfer performance whereas the fluid inlet temperature to the radiator has trivial effect. They showed that application of the nanofluid with =1% can enhance heat transfer efficiency up to 45% in comparison with pure water.

Peyghambarzadeh et al. [7] conducted another experimental investigation in order to examine the forced convective heat transfer enhancement by employing nanofluids in an automobile radiator. They added Al2O3 nanoparticles to water, Ethylene Glycol and EG-w mixtures with different volumetric concentrations and observed significant increase for total heat transfer rates. They also observed that the Nusselt number enhanced up to 40% for the nanofluids at the best conditions. Furthermore, their experimental results demonstrated that the heat transfer

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behaviors of the nanofluids were highly dependent on the nanoparticles volume fraction and the flow conditions, but are weakly dependent on the temperature. They also reported that Nu correlations given by Li and Xuan [5] and Xuan and Li [8] had good agreement with their experimental results for both the laminar and the turbulent regimes.

Fakhari and Sheikhzadeh [9] reviewed all previous studies which have been carried out on the subject of nanofluids application in the automotive radiator. They compared the results reported by the previous researchers. Also, by curve fitting the experimental results of Peyghambarzadeh et al. [6, 7] they presented two new Nu correlations for both laminar and turbulent flows.

Sheikhzadeh et al. [10] investigated the effects of using Cu-EG nanofluid with =0-5% in a typical automotive radiator. They reported that using the nanofluid with =5% results in: (a) 63.4% increase in overall heat transfer coefficient based on the air side, (b) 29.6% enhancement in heat transfer rate, (c) reduction of outlet coolant temperature.

Heat transfer and friction factor of an automotive radiator by using TiO2 and SiO2 nanoparticles dispersed in water as a base fluid was studied experimentally by Hussein et al. [11]. The range of Reynolds number and volume fraction are (250-1750) and (1-2.5 %), respectively. According to their results, a highest Nusselt number have been recorded up to 16.4 and 17.85 for TiO2-W and SiO2-W respectively.

Sheikhzadeh et al. [12] studied experimentally the heat transfer of Al2O3-EG-water nanofluid in an automobile cooling system. According to their results, both the convective heat transfer coefficient and Nusselt number increase (about 9%) with increasing the coolant flow rate. Also, they developed a new empirical correlation for average Nusselt number of Al2O3-EG-water nanofluid in developing region of flat tubes of automotive radiator for laminar flow and its maximum error was 3%.

So far, several theoretical and experimental studies on heat transfer and pressure drop of the nanofluids in automotive radiators have been performed. The theoretical ones (except [3]) used the temperature independent models for thermophysical properties of nanofluids which brought in many errors in the calculations. The studies of Peyghambarzadeh et al. [6, 7] not only had the errors of using temperature independent models, but also had several mistakes in calculations of hydraulic diameter, Reynolds number and subsequently Nusselt number. Now the question is what is the real effect of the nanofluids on heat transfer and pressure drop as working fluid inside the automotive radiator? This study attempts to investigate experimentally the effect of using alumina nanofluid with EG-water base fluid (60:40 by mass) on thermal performance of automotive radiator and the coolant pressure drop.

2. . Experimental setup

The schematic diagram of the experimental set up is shown in Figure 1. The experimental setup includes an automotive radiator with a fan, reservoir, expansion resource, heater, thermometers, pressure gauges, pump, rotameter, miniature fuses, tubes and connectors.

Some characteristics of the automotive radiator are mentioned in Tables 1-3 and Figure 2.

Table 1. Dimensions of the typical automotive radiator

height	length	width
330 mm	364 mm	27 mm

Table 2. Characteristics of the automotive radiator fins

type	material	thickness	spacing
helical	Aluminium	0.11 mm	1.84 mm

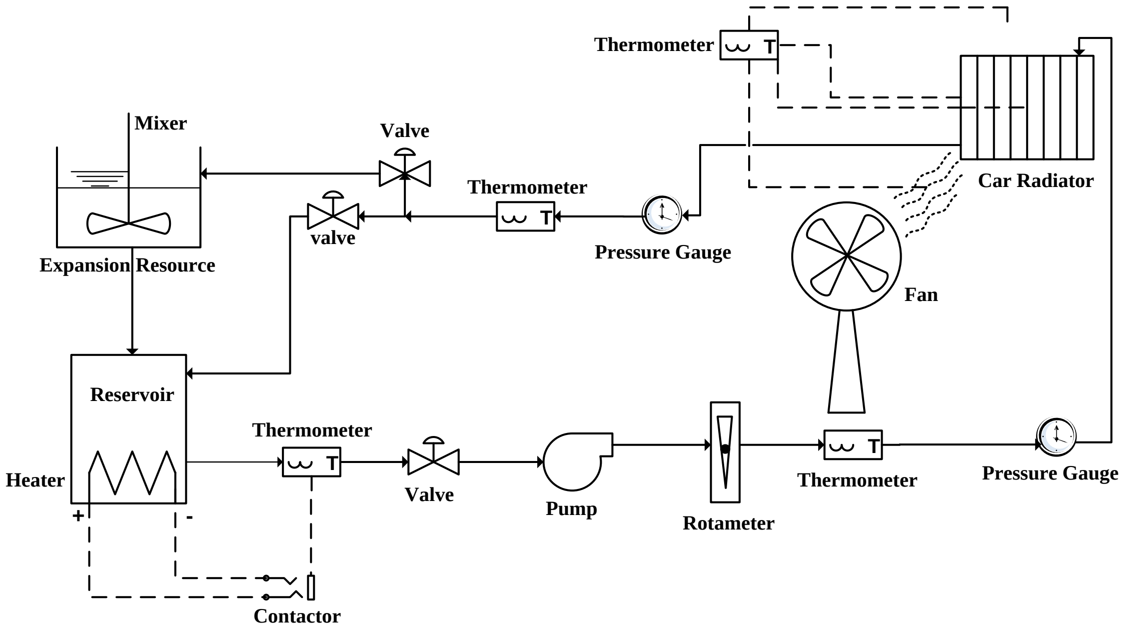

Figure 1. A schematic diagram of the experimental set up

Table 3. Characteristics of the automotive radiator tubes

Inner dimension	Number of tubes	material	spacing	thickness	Hydraulic diameter
1.5×21.6×300 (mm)	34	Aluminium	8.02 mm	0.18 mm	2.84 mm

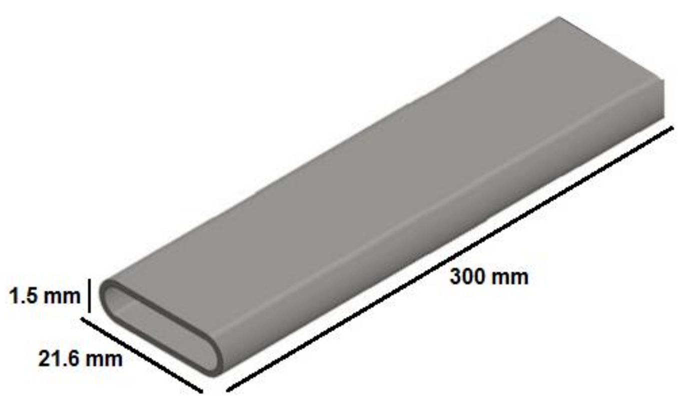

Figure 2. Schematic and dimensions of the radiator flat tube

Three thermometers (Model: SAMWON ENG) have been used to measure the coolant

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temperature. Also an Autonics thermometer (model: T4WM) has been applied to measure air input and output temperatures as well as temperatures of front and rear surfaces of the radiator. The thermometers have the measurement accuracy of 0.1 oC and their temperature sensors are RTD (PT100 type).

A centrifugal pump of DAB ™ A50-180M model has been used. The pump has the capacity to tolerate high temperatures up to 110 °C. There are two other reasons for this selection. Firstly, the automotive water pumps are generally centrifugal and secondly, when the output of the pump is closed, pump is not damaged.

To measure the volumetric flow rate of the circulating base fluid, a rotameter has been used which has the measurement range of 2-8 lit/min and the accuracy of 1lit/min. After being installed as part of the experimental setup, the rotameter has been calibrated for various temperatures. Since the nanofluid has milky color and consequently the central trackball of rotameter is not visible, direct measurement method has been used to measure the nanofluid flow rate. For this purpose and for every case, the experiment has been conducted first for the approximate desired flow rate until the steady state statues has been found. Then, the nanofluid flow rate has been measured by measuring the passage time of a certain volume of the nanofluid in the steady state temperature. For every flow rate, the measurement has been repeated three or four times and the average values have been accepted as the volumetric flow rate.

Because of the method used to measure the nanofluid flow rate, a limitation is made by shrinking the size of reservoir, that is, reduction in the passage time of the nanofluid volume and consequently, reduction in measurement accuracy of its flow rate. However, due to the high cost of the nanofluid preparation, a high volume reservoir could not be used. To this end, a cylindrical reservoir with 12cm diameter and 20cm height has been constructed and embedded in the experimental setup. In order to fill and bleed the setup and also to create the necessary space for coolant expansion, an expansion resource has been perched over the reservoir and at the highest point of the setup. A 4000 W electrical element to heat the working fluid has been placed in the reservoir.

To measure the fluid pressure drop inside the radiator, two 0-600 mbar pressure gauges having the accuracy of 10 mbar have been used.

3. Nanofluid preparation

In general, there are two methods for preparing nanofluids, namely, single-step and two- step methods. In this study, the two-step method has been used. At the first step of two-step method, the nanoparticles have been prepared as a dry powder. In the present work, -alumina nanoparticles have been purchased from “Nano Pars Lima” company with the characteristics presented in Table 4. Also, TEM image of the Al2O3 nanoparticles, shown in Figure 3.

Table 4. Some characteristics of γ -alumina nanoparticles.

properties	value
Appearance	White powder
Purity	+99%
Average particle size	20 nm
Specific surface area	>138 m^2/g
Ca	$\leq$ 25 ppm
V	$\leq$ 7 ppm
Cl	$\leq$ 315 ppm
Na	$\leq$ 70 ppm
Mn	$\leq$ 3 ppm
Co	$\leq$ 2 ppm

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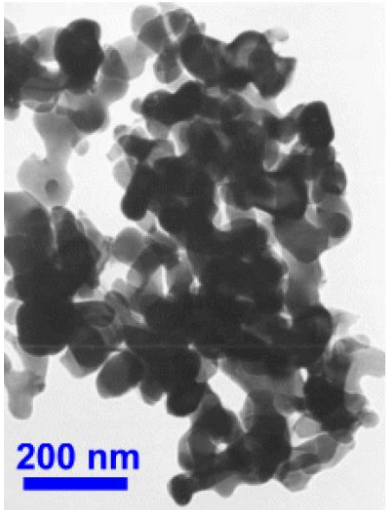

Figure 3. TEM image of the Al_2O_3 nanoparticles

In the second step and in order to disperse the nanoparticles in the fluid, while the magnetic mixer has been used nanoparticles have been poured into the mixture of distilled water and Ethylene Glycol (60:40 by mass). Since the nanoparticles have a high surface energy, Van der Waals forces between the nanoparticles make some of them being clustered instead of complete dispersion. Therefore, to solve this problem, the solution has been exposed to ultrasonic waves for 4 hours to break up the clods and to prepare a homogeneous nanofluid. It is worth mentioning that the nanoparticles deposition is not observed until the nanofluid becomes stagnant or quasi-stagnant (with low speed). As the nanofluid passes through the pump, it undergoes high shear and stress tensions; thus clustering is removed [12]. Additionally, high flow rate in the radiator tubes and connecting pipes improves the stabilization of the nanofluid. In this study, no dispersant or stabilizer has been added to the nanofluid. This is due to the fact that the addition of any agent may change the nanofluid properties (especially at temperatures above 60 °C) [1, 12, 13] and the wish was to simulate the actual condition encountered in the automotive radiator.

4. Thermophysical properties

In this study the nanofluid properties are calculated using the temperature-dependent correlations which have been published recently in the literature. According to wide temperature variations during each test, using temperature-dependent correlations makes the results free of errors and assumptions which are observed in previous similar studies.

As described by Vajjha et al. [14], the best correlation for density of Al2O3 nanoparticles dispersion in 60:40 EG-water is the theoretical equation given by Pak and Cho [13]. Therefore, this density equation is adopted in the present work as [12]:

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_f \tag{1}$$

The specific heat of Al_2O_3-EG-w nanofluid for 60:40 EG/w is, [15]:

$$\frac{c_{p,nf}}{c_{p,f}} = \frac{0.0008911\,T + 0.5179\dfrac{c_{p,p}}{c_{p,f}}}{0.425+\varphi} \tag{2}$$

Sahoo et al. [16] measured the viscosity of Al_2O_3-EG-w nanofluid for volume fractions up to 10%. For the temperature range of 273 to 363 K, they proposed [15]:

$$\mu_{nf} = 2.392\times10^{-7}\exp\left(\frac{2903}{T}+12.65\varphi\right) \tag{3}$$

Vajjha and Das [17] measured the thermal conductivity of Al_2O_3-EG-w nanofluid for 60:40 EG-w. They developed a thermal conductivity model as a two-term function in the temperature range of 298 to 363 K as [18]:

$$k_{nf} = \frac{k_P + 2k_f - 2(k_f - k_P)\phi}{k_P + 2k_f + 2(k_f - k_P)\phi}k_f + 5\times10^4 B\phi\rho_f c_{P,f}\sqrt{\frac{\kappa T}{\rho_P d_P}}f(T,\phi) \tag{4-a}$$

where $f(T,\varphi)$ is:

$$f(T,\phi) = \left(2.8217\times10^{-2}\phi + 3.917\times10^{-3}\right)\frac{T}{T_o} + \left(-3.0669\times10^{-2}\phi - 3.91123\times10^{-3}\right) \tag{4-b}$$

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and $B = 8.4407\,(100\,\varphi)^{-1.07304}$

The above relations for the nanofluid thermophysical properties require properties of both the nanoparticles and the base fluid. Properties of the nanoparticles are presented in Table 5.

Table 5. Properties of nanoparticles at temperature of 300 K [19]

nanoparticles	ρ (kg m^{-3})	c_p (J kg^{-1} K^{-1})	k (W m^{-1} K^{-1})
Al_2O_3 (20 nm)	3970	765	36

The properties of the 60:40 EG-water as the base fluid considered as functions of temperature are [12]:

$$\rho_f = -2.43\times10^{-3}T^2 + 0.96216\,T - 1009.9261 \quad (5)$$

$$c_{p,f} = 4.2483T + 1882.4 \quad (6)$$

$$\mu_f = 5.55\times10^{-7}\exp\left(\frac{2664}{T}\right) \quad (7)$$

$$k_f = -3.196\times10^{-6}T^2 + 2.51188\times10^{-3}T - 0.105411 \quad (8)$$

The Equations (5-8) are valid within the temperature range of 293 K<T<363 K.

To evaluate heat transfer rate at the air side, thermophysical properties of air are needed. The density and specific heat of air are calculated as a function of temperature, within the temperature range of 20-60 ºC, from:

$$\rho_a = 1.294824 - 0.00788T + 0.00092T\times \mathrm{Ln}(T) + 1.389225\times10^{-30}e^{T} - 11473194e^{-T} \qquad R^2 = 0.999 \quad (9)$$

$$\frac{1}{c_{p,a}} = 0.994775 - 1.394156\times10^{-7}T^2 \times \mathrm{Ln}(T) + \frac{0.04615}{T^{3/2}} \qquad R^2 = 0.999 \quad (10)$$

The equations (9) and (10) have been obtained by curve fitting using the data of [19].

5. Mathematical formulation

5.1. Heat transfer

In order to calculate the heat transfer, some assumptions have been used which are listed below:

A. Radiator tubes wall temperature is assumed to be constant. Radiator wall temperature is measured using two thermometers mounted on both sides of it; the average value of them has been considered as wall temperature throughout the radiator.

B. The contact thermal resistance of the thermometers is ignored.

C. Due to the very small thickness and high thermal conductivity of the radiator tubes walls, it is reasonable to equate the inside temperature of the tubes with the outside ones. Thus, the conduction thermal resistance of the radiator wall and deposition resistance are neglected.

The heat transfer rate from the coolant flow is:

$$q_c = \dot{m}_c\, c_{p,c}\left(T_{c,i} - T_{c,o}\right) \quad (11)$$

The heat transfer rate to the air flow is:

$$q_a = \dot{m}_a\, c_{p,a}\left(T_{a,i} - T_{a,o}\right) \quad (12)$$

The values of qa and qc should be theoretically equal, but slight differences between them have been observed in the experiments. So the average value of qa and qc has been used in the calculation.

$$q = \frac{q_c + q_a}{2} \quad (13)$$

Also, according to Newton's cooling law, the heat transfer rate from hot fluid to radiator tube wall is:

$$q = hA\left(T_b - T_{wall}\right) \quad (14)$$

Therefore the convective heat transfer coefficient is:

$$h = \frac{q}{A\left(T_b - T_{wall}\right)} \quad (15)$$

And the average Nusselt number is defined as:

$$Nu = \frac{hd_h}{k} = \frac{qd_h}{Ak\left(T_b - T_{wall}\right)} \quad (16)$$

where A is peripheral area of radiator tubes, T_b is bulk temperature which has been assumed to be the average values of inlet and outlet temperature of the fluid moving through the radiator and T_{wall} is tube wall temperature. It should also be mentioned that all of thermophysical properties have been calculated at fluid bulk temperature.

5.2. Merit parameter

Use of nanofluid instead of pure fluid has both positive and adverse effects. The positive effect is heat transfer enhancement and the adverse one is increase in pressure drop and consequently required pumping power. Therefore, in order to investigate the actual effect of using the nanofluid, Merit parameter [20] is used as.

$$Me = \frac{q}{P} \quad (17)$$

where pumping power is:

$$P = Q \times \Delta P \quad (18)$$

5.3. **Automotive** radiator **thermal efficiency**

The automotive radiator is a compact heat exchanger and its effectiveness is calculated as:

$$\varepsilon = \frac{q_{act}}{q_{max}} = \frac{q}{C_{min}\Delta T_{max}} = \frac{q}{\dot{m}_a\, c_{p,a}\left(T_{c,i} - T_{a,i}\right)} \quad (19)$$

In this study, for the nanofluids with different volume fractions and the base fluid at all of the flow rates, $\dot{m}_c\, c_{p,c} > \dot{m}_a\, c_{p,a}$. Therefore, C_{min} is always for the air side.

5.4. Uncertainty

In experimental works, data uncertainty must be calculated. Uncertainty shows what extent a researcher is certain about the results. In general, it is assumed that Z is a function of n variables from x_1 to x_n with known uncertainties. Therefore, the following equation can be used to calculate uncertainty of the results [12].

$$Z = Z(x_1, x_2, x_3, \ldots) \Rightarrow (\delta Z)^2 = \left(\frac{\partial Z}{\partial x_1}\delta x_1\right)^2 + \left(\frac{\partial Z}{\partial x_2}\delta x_2\right)^2 + \left(\frac{\partial Z}{\partial x_3}\delta x_3\right)^2 + \ldots \quad (20)$$

The data uncertainty is calculated for all quantities [12, 21, 22]. The variables uncertainties at maximum value of coolant flow rate, nanoparticles volume fraction and air velocity are presented in Table 6. On the other hand, the uncertainties are shown for some quantities at results section.

6. Results

The experimental tests have been performed with nanofluids with four nanoparticles volume fractions of 0.003, 0.006, 0.009 and 0.012. Also tests have been performed for EG-water (60:40 by mass) as the base fluid. To investigate the effect of coolant flow rate, the experiments have been conducted for three flow rates of 9, 11 and 13 lit/min. Also the effect of air flow rate has been investigated by performing tests for two air velocities of 3.75 and 2.85 m/s.

Table 6. Value and uncertainty of variables at maximum value of coolant flow rate, nanoparticles volume fraction and air velocity.

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variable	value	uncertainty
Q (lit/min)	13	0.0715
Re	347.8116	3.0607
q (W)	5167.2656	91.473
Nu	6.4796	0.11
ΔP (Pa)	9112.0910	850
$\frac{\Delta P_{nf} - \Delta P_f}{\Delta P_f}$	0.3807	0.05
ε	0.5734	0.014
Me (W/Pa)	43.6214	0.02

6.1. The effect of nanoparticles volume fraction

In this section, the results for different nanoparticles volume fractions and at constant coolant flow rate of 11 lit/min and air velocity of 3.75 m/s are presented and discussed. As it is observed from Figure 4, by increasing nanoparticles volume fraction, the mass flow rate increases due to density enhancement of the nanofluid.

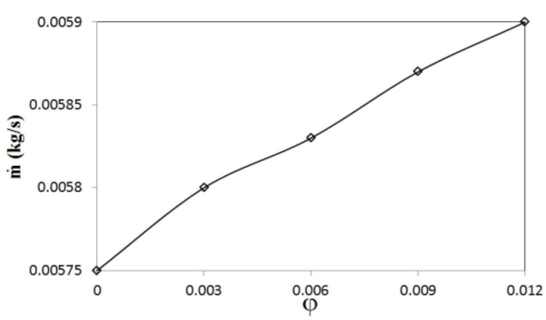

Figure 4. Effect of the nanoparticles volume fraction on coolant mass flow rate at constant coolant volumetric flow rate.

The variations of heat transfer rate with nanoparticles volume fraction are shown in Figure 5. The heat transfer rate is increased exponentially as the nanoparticles volume fraction is increased such that for the nanofluid with φ =0.012 the relative enhancement compared to that of the base fluid is 8.1% (at constant coolant flow rate of 11 lit/min) [12].

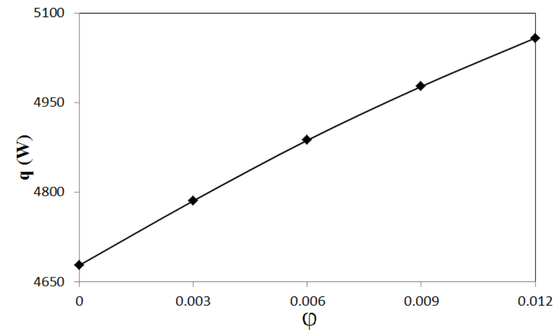

Figure 5. Variations of heat transfer rate with φ at constant coolant (Q=11 lit/min) and air flow rate

The variation of convective heat transfer coefficient with nanoparticles volume fraction is shown in Fig. 6. As the nanoparticles volume fraction increases, the convective heat transfer coefficient enhances such that for the nanofluid with φ =0.012 the relative enhancement compared to that of the base fluid is 10% (at constant coolant flow rate of 13 lit/min).

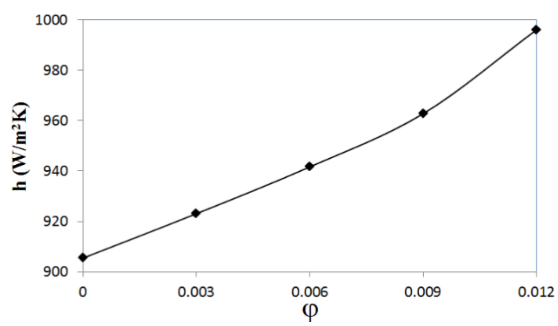

Fig. 6. Variations of convective heat transfer coefficient with φ at coolant flow rate of 13 lit/min.

Figure 7 illustrates that when nanofluid with φ =0.003 is used, the Nusselt number decreases compared with that of base fluid, but by increasing it further the Nusselt number increases. It should be noted that although adding the nanoparticles results in an increase in the heat transfer as well as in the convective heat transfer coefficient, the thermal conductivity enhances too [12]. For example, the thermal conductivity of nanofluid with φ =0.012 is 16.33% higher than that of the base fluid. This increase in thermal

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conductivity is higher than the enhancement of convective heat transfer coefficient. As a result for the whole range of volume fractions of this study the Nusselt number of the nanofluid is less than that of the base fluid. The same behavior was observed in the experimental work of Vajjha et al. [3] and Sheikhzadeh et al. [12], but Peyghambarzadeh et al. [7] and Hussein et al. [11] reported that the nanofluid Nusselt number was always higher than that of the base fluid for laminar regime. The difference seems to be related to the nanofluid thermal conductivity model utilized by them. Peyghambarzadeh et al. [7] employed the mathematical model of Hamilton-Crosser, which underestimates the thermal conductivity of nanofluid [17]. Also Hussein et al. [11] used constant value for the nanofluids thermophysical properties which brought in many errors in the calculations [12].

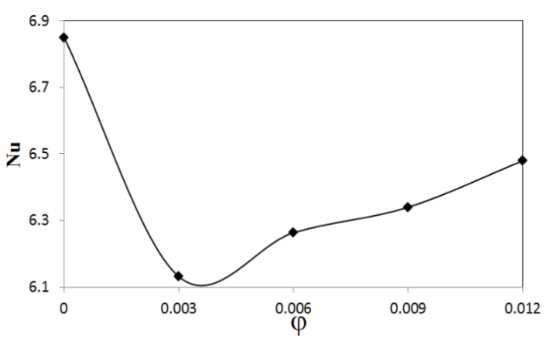

Figure 7. Variations of Nu with φ at constant coolant flow rate of 13 lit/min

6.2. The effect of coolant flow rate

In this section the effect of coolant flow rate on the heat transfer at constant air velocity of 3.75 m/s is presented. Coolant flow rate plays a vital role in determining the radiator's thermal performance. If the coolant flow rate is not properly controlled, the engine becomes either overcooled or overheated. The main task is to ensure that engine is operating at optimum temperature by not only controlling the coolant flow rate but also the air flow rate. Although the coolant pump is usually driven by the engine, thermostat is also playing an important role to control the coolant flow rate. Thus all of the tests in this study have been begun from temperature of 90 ºC, which is almost the opening temperature of thermostats.

Variations of heat transfer rate in terms of the coolant volumetric flow rate are shown in Figure 8. As it observed, as coolant flow rate increase, heat transfer enhances. This enhancement is higher for nanofluids compared with that of base fluid. For example, the heat transfer rates of the nanofluid with φ =0.012 and base fluid at Q=13 lit/min, enhance 5.6% and 3.4% compared to those of Q=9 lit/min, respectively.

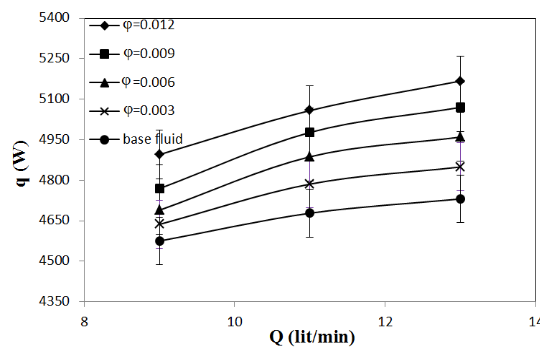

Figure 8. Variations of heat transfer rate with coolant volumetric flow and φ at constant air velocity

6.3. The effect of the air velocity

The effect of the air velocity and consequently the air flow rate passing on the radiator surfaces on the heat transfer is discussed in this section. As shown in Figure 9, increase in air velocity increases heat transfer rate. For instance, at constant coolant flow rate of 13 lit/min, the heat transfer rate of the nanofluid with φ =0.012 and the base fluid at the air velocity of 3.75 m/s, increase by 8% and 8.6% respectively compared to those of the air velocity of 2.85 m/s.

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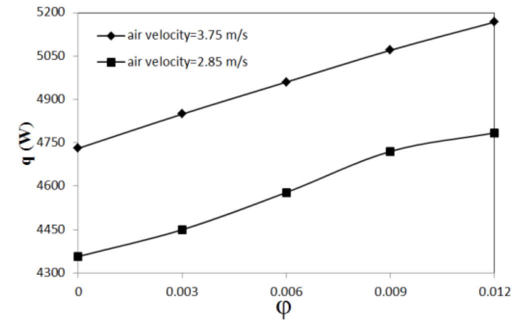

Figure 9. Variations of heat transfer rate with φ and air velocity at constant coolant flow rate

In this section, the results for the coolant pressure drop for different coolant volumetric flow rates, Reynolds number and nanoparticles volume fractions at fixed air velocity of 3.75 m/s are presented. As shown in Figure 10, increasing the coolant flow rate, Re and nanoparticles volume fraction leads to increase in the pressure drop. It is seen that the pressure drop increase with flow rate or Re is very significant. For example, at fixed flow rate of 13 lit/min, pressure drop for the nanofluid with φ =0.012 is 38.1% more than that of the base fluid. On the other hand, at fixed volume fraction of 0.012, the nanofluid pressure drop for the flow rate of 13 lit/min (Re=335.42) is 706.5% more than that for Q=9 lit/min (Re=224.6).

6.4. Pressure drop

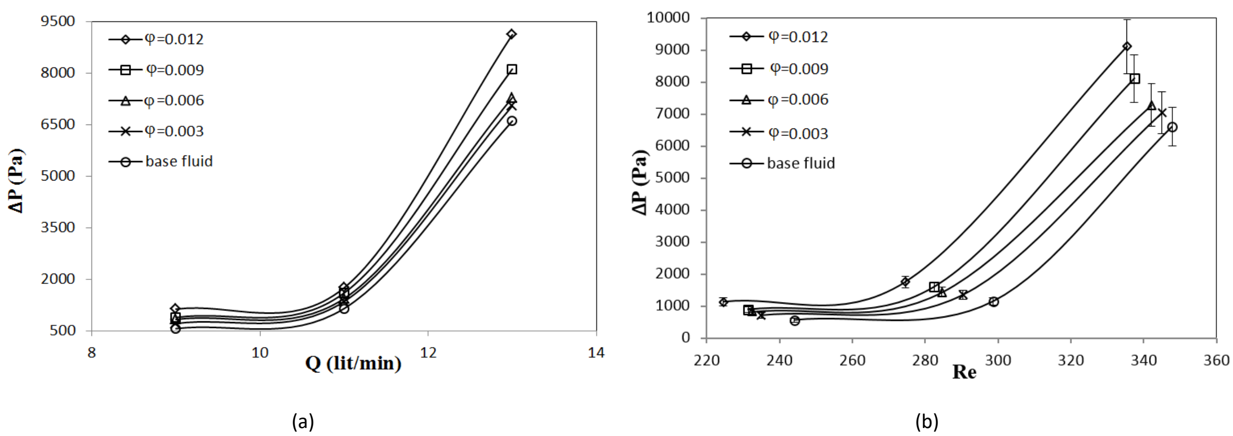

Figure 10. Variations of coolant pressure drop with φ and a) coolant flow rate, b) Re number, at constant air velocity

6.5. Relative nanofluid pressure drop

The pressure drop of the nanofluid relative to that of the base fluid is an important parameter. In this section, its variation at different flow rates and nanoparticles volume fractions for the air velocity of 3.75 m/s is discussed. As shown in Figure 11, increase in the nanofluid flow rate results in reduction of the relative pressure drop of nanofluid. For example, for the nanofluid with φ =0.012, the relative pressure drop of nanofluid at Q=13 lit/min reduces 62.3% compared to that of Q=9 lit/min. It is seen that its variations is milder with the nanoparticles volume fraction compared to the flow rate.

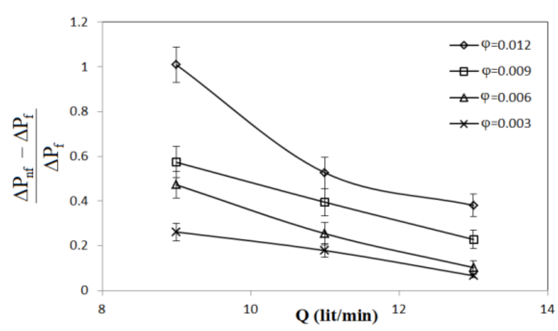

Figure 11. Variations of the relative pressure drop of nanofluid with coolant flow rate and φ at constant air velocity

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6.6. Comparison of Merit parameter

As previously mentioned, Merit parameter is important for heat exchangers, especially when the nanofluids are used. This section investigates Merit parameter of the radiator for different nanoparticles volume fractions and flow rates at constant air velocity of 3.75 m/s.

As shown in Figure 12, by increasing coolant flow rate and nanoparticles volume fraction, Merit parameter reduces. For example, at a fixed flow rate of 13 lit/min, Merit parameter of the nanofluid with φ=0.012 reduces 20.9% compared to that of the base fluid. On the other hand, at fixed nanoparticles volume fraction of 0.012, Merit parameter for the nanofluid at Q=13 lit/min is 90.9% less than that of Q=9 lit/min. The results indicate that although replacing the base fluid by the nanofluid increases heat transfer, it results in further increase in the pressure drop and consequently required pumping power.

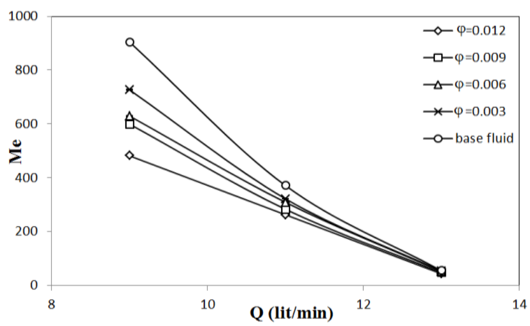

Figure 12. Variations of Merit parameter with coolant volumetric flow and φ at constant air velocity

6.7. Comparison of radiator thermal efficiency

Variations of the radiator thermal efficiency in terms of flow rates for different nanoparticles volume fractions but constant air velocity of 3.75 m/s are shown in Figure 13. It is observed that by increasing coolant flow rate and nanoparticles volume fraction, radiator thermal efficiency increases. For example, at a fixed flow rate of 13 lit/min, the radiator thermal efficiency using the nanofluid with φ=0.012 increases 9.5% compared to that of the base fluid. On the other hand, at fixed nanoparticles volume fraction of 0.012, the radiator thermal efficiency using the nanofluid at Q=13 lit/min is 9.4% more than that of Q=9 lit/min.

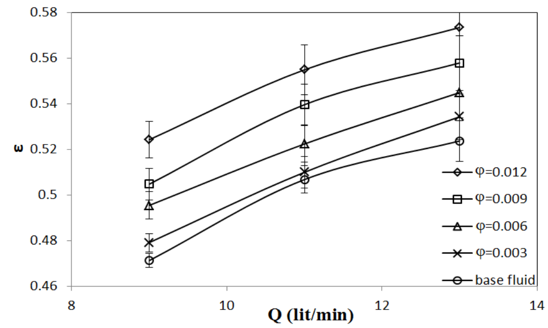

Figure 13. Variations of thermal efficiency of radiator with coolant volumetric flow and φ at constant air velocity

7. Conclusion

In this study, heat transfer and pressure drop of Al2O3-EG-water nanofluid under laminar regime in an automotive radiator have been investigated. For this purpose an experimental setup has been designed and constructed. The experiments have been performed for the base fluid and nanofluid with different volume fractions and for various coolant flow rates and two air flow velocities. The thermophysical properties have been calculated using the recent temperature dependent models presented in the literature. According to the results, the heat transfer and pressure drop were increased with increasing coolant flow rate and nanoparticles volume fractions. Also, by adding the nanoparticles, Nusselt number first decreases, and then it increases by increasing nanoparticles volume fraction. For instance, for the nanofluid with φ=0.012 at the fixed flow rate of 13 lit/min (Re=335.42):

a) The heat transfer rate of the nanofluid increased 9.2% compared to the base fluid.

b) The pressure drop of the nanofluid increased 38.1% compared to the base fluid.

c) By increasing the air velocity from 2.85 to 3.75 m/s, the heat transfer rate increased 8%.

d) By using the nanofluid, the radiator thermal efficiency increased 9.5% compared to the base fluid.

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e) Merit parameter of the nanofluid reduces 20.9% compared to that of the base fluid.

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9. References

[1] Wang X-Q, Mujumdar AS. A review on nanofluids-part II: Experiments and applications, Braz. J. Chem. Eng., 2008, 25: 631--648.

[2] Singh D, Toutbort J, Chen G. Heavy vehicle systems optimization merit review and peer evaluation, Argonne National Laboratory, 2006.

[3] Vajjha RS, Das DK, Namburu PK. Numerical study of fluid dynamic and heat transfer performance of Al_2O_3 and CuO nanofluids in the flat tubes of a radiator, Int. J. Heat Fluid Flow, 2010, 31: 613--621.

[4] Sheikhzadeh GA, Fakhari MM. Investigation of heat transfer in a flat tube of an automobile radiator using Al_2O_3 nanofluid, in: Proceedings of 7th International Conference on Computational Heat and Mass Transfer, Istanbul, Turkey, 2011.

[5] Li Q., Xuan Y. Convective heat transfer and flow characteristics of Cu–water nanofluid, Science in China, Series E: Technological Sciences, 2002, 45 (4): 408--416.

[6] Peyghambarzadeh SM, Hashemabadi SH, Jamnani MS, Hoseini SM. Improving the cooling performance of automobile radiator with Al_2O_3/water nanofluid, Appl. Therm. Eng., 2011, 31: 1833--1838.

[7] Peyghambarzadeh SM, Hashemabadi SH, Hoseini SM, Jamnani MS. Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators, Int. Commun. Heat Mass Transfer, 2011, 38: 1283--1290.

[8] Xuan Y, Li Q. Investigation on convective heat transfer and flow features of nanofluids, J. Heat Transfer, 2003, 125: 151--155.

[9] Fakhari MM, Sheikhzadeh GA. A Critical Review on Application of Nanofuids as Coolants in Automobile Radiators, in: Proceedings of Iran-Belarus International Conference on Modern Applications of Nanotechnology (IBCN12), Minsk, Belarus, 2012.

[10] Sheikhzadeh GA, Hajilou MH, Jafarian H. Analysis of thermal performance of a car radiator employing nanofluid, Int. J. Mechanical Engineering Applications, 2014, 2 (4): 47--51.

[11] Hussein A., Bakar R.A., Kadirgama K., Sharma K.V. Heat transfer augmentation of a car radiator using nanofluids, Heat Mass Transfer, 2014, 50: 1553--1561.

[12] Sheikhzadeh GA, Fakhari MM, Khorasanizadeh H. Experimental Investigation of Laminar Convection Heat Transfer of Al_2O_3-Ethylene Glycol-Water Nanofluid as a Coolant in a Car Radiator, J. Appl. Fluid Mech., 2017, 10 (1): 209--219.

[13] Pak BC, Cho YI. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Exp. Heat Transfer, 1999, 11: 151--170.

[14] Vajjha RS, Das DK, Mahagaonkar BM. Density measurements of different nanofluids and their comparison with theory, Petroleum Science Technology, 2009, 27, (6): 612--624.

[15] Khorasanizadeh H, Fakhari MM, Ghaffari SP. Effects of Properties Variations of Al_2O_3-EG-water Nanofluid on Buoyancy-driven Heat Transfer in a Two-dimensional Enclosure; Enhancement or Deterioration?, Heat Mass Transfer, 2015, 51 (5):671--684.

[16] Sahoo BC, Vajjha RS, Ganguli R, Chukwu GA, Das DK. Determination of rheological behavior of aluminum oxide nanofluid and development of new viscosity correlations, Petroleum Science Technology, 2009, 27: 1757--1770.

[17] Vajjha RS, Das DK. Experimental determination of thermal conductivity of three

[DOI: 10.22068/ase.2019.444]

nanofluids and development of new correlations, Int. J. Heat Mass Transfer, 2009, 52: 4675--4682

[18] Khorasanizadeh H, Fakhari MM, Ghaffari SP. Investigation of Heat Transfer Enhancement or Deterioration of Variable Properties Al_2O_3-EG-water Nanofluid in Buoyancy Driven Convection, Transp. Phenom. Nano Micro Scales, 2014, 2 (1): 50--67.

[19] Incropera FP, DeWitt DP. Introduction to Heat Transfer, fourth ed., John Wiley & Sons, Inc., New York, 1996.

[20] Yu W. Nanofluids for Thermal Conditions-Underhood Heat Transfer, Argonne National Laboratory, 2009.

[21] Fakhari MM. Experimental study of effect of using Al_2O_3-Ethylene Glycol-water nanofluid as working fluid in car radiator system, M.Sc. thesis, University of Kashan, Kashan, Iran, 2012.

[22] Sheikhzadeh GA, Fakhari MM. Experimental study of effect of using Al_2O_3-Ethylene Glycol-water Nanofluid on Thermal performance of Car Radiator, in: Proceedings of 21st Annual International Conference on Mechanical Engineering, Tehran, Iran, 2013.

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