Heat Transfer Enhancement of Car Radiator Using Al_2O_3/ Water Nanofluid in the Presence of Electric Field; an Experimental Study

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Abstract: In this experimental study, Aluminums Oxide (Al_2O_3) in Pure Water (PW) as nanofluid was used for heat transfer enhancement in car radiator together with electric field. Electric field with different voltage 8, 11, 14 kV and nanofluids with volume concentrations of 0.08%, 0.5% and 1% were investigated. From the experiments, it was found that the unit with electric field pronounced better heat transfer rate, especially at low fan speed. In addition heat transfer coefficient and heat transfer rate in engine cooling system increased with the usage of nanofluids Al_2O_3/PW compared to Pure Water alone. With the use of nanofluid with concentration of 1% and electric field for fan speed 600 and 1200 rpm, thermal performance factors were in a range between, 1.8-3.2 and 1.6-1.74, respectively. Thermal performance factor is more than 1 in all of cases, and it can be concluded that this technique can be used in car radiators to improve heat transfer.
Keywords: heat dissipation enhancement, car radiator, electric field, nanofluid

1. Introduction

Car radiator is one type of cross flow and compact heat exchanger. It is an important part of cooling system in vehicle engine because a lot of energy is wasted by this system. Therefore, if even for a short time the cooling system cause the problem or it unable to perform his work well, it can lead to increase fuel consumption, increase pollution and this could cause irreparable damages to the vehicle engine components. Due to the reduction of fuel consumption in engine and power consumption reduction in cooling system, optimization of the cooling system and its performance improvements is necessary. Therefore, researchers have forced to think about the different ways to enhance heat transfer and increase the cooling system performance in the engine. There are several methods to improve the performance of the cooling system. These methods can be divided into active and passive methods. The active techniques require additional external power such as surface vibration and fluid injection. The passive techniques do not require direct input of external power [1].

Selvam et al. [2] presented an experimental study of enhanced heat transfer performance of an automobile radiator with graphene based suspensions. The volume concentrations of graphene Nano platelets were varied from 0.1% to 0.5%. Mass flow rate of nanofluids were varied from 10 to 100 g/s. Nanofluid inlet temperature was considered as 35 ℃ and 45 ℃ while the ambient air velocity was fixed as 3 m/s for the convective heat transfer experiments. The enhancement of convective heat transfer coefficient for the highest concentration (0.5 vol%) and highest mass flow rate (100 g/s) was found to be 20% and 51% when the nanofluid inlet temperature was 35 ℃ and 45 ℃ respectively. Li et al. [3] experimentally studied on the thermo-physical properties of car engine coolant (water/ethylene glycol mixture) based SiC nanofluids. They reported the new results on the thermal conductivity and viscosity of car engine coolants based silicon carbide (SiC) nanofluids. It was found that the thermal conductivity of nanofluids increased with the volume fraction and temperature (10-50°C), and the highest thermal conductivity enhancement was found to be 53.81% for 0.5 vol. % nanofluid at 50 °C. Their results showed that the overall effectiveness of nanofluids with 0.2 vol.% was found to be ~1.6. Sandhya et al. [4] conducted an experimental study to improving the cooling performance of automobile radiator using ethylene glycol/ water based T_iO_2 nanofluids. 40% ethylene glycol and 60% water with volume concentrations of 0.1%, 0.3% and 0.5% of T_iO_2 nano powder are used. Their experiments were conducted in the range of Reynolds numbers from 4000 to 15,000. Also, their results demonstrated that increasing the fluid circulation rate can improve the heat transfer performance while

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the fluid inlet temperature to the radiator has little or no effect. Muhammad Ali et al. [5] presented an experimental study of heat transfer augmentation for car radiator using ZnO-water nanofluids in different volumetric concentrations (0.01%, 0.08%, 0.2% and 0.3%). They showed that the best heat transfer enhancement up to 46% was found compared to base fluid at 0.2% volumetric concentration. Also, a further increase in volumetric concentration to 0.3% is shown a decrease in heat transfer enhancement compared to 0.2% volumetric concentration. Nieh et al. [6] presented an experimental study on heat dissipation in car radiator using oxide nano-coolant. They adopted an alumina (Al_2O_3) and titania (T_iO_2) nano-coolant (NC) to enhance the heat dissipation performance of an air-cooled radiator. Their results showed that the heat dissipation capacity and the efficiency factor of the NC are higher than EG/W, and that the T_iO_2 NC is higher than the Al_2O_3 NC according to most of the experimental data. The maximum enhanced ratios of the heat dissipation capacity, pressure drop, pumping power, and efficiency factor for all the experimental parameters are approximately 25.6%, 6.1%, 2.5%, and 27.2%, respectively, compared with EG/W. Peyghambarzadeh et al. [7] experimentally studied the overall heat transfer coefficient in the application of dilute nanofluids (Copper oxide (CuO) and Iron oxide (Fe_2O_3). Nanoparticles are added to the water at three concentrations (0.15, 0.4, and 0.65 vol.%) in the car radiator. They evaluated the heat transfer performance of the automobile radiator by calculating the overall heat transfer coefficient (U) according to the conventional ε-NTU technique. Their results demonstrated that both nanofluids show greater overall heat transfer coefficient in comparison with water up to 9%. They also observed that increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient. Naraki et al. [8] experimentally studied the overall heat transfer coefficient of CuO/water nanofluids under laminar flow regime ($100 < Re < 1000$) in a car radiator. They showed that the overall heat transfer coefficient with nanofluid is more than the base fluid. Also, they showed that the overall heat transfer coefficient increased with the enhancement in the nanofluid concentration from 0 to 0.4% concentration. Ravikant et al. [9] presented a numerical study of fluid dynamic and heat transfer of Al_2O_3 and CuO nanofluids in the flat tubes of a radiator. A three-dimensional laminar flow with two different nanofluids, Al_2O_3 and CuO, in an Ethylene Glycol and water mixture circulating through the flat tubes of an automobile radiator studied to evaluate their advantage over the base fluid numerically. Their results for the local and the average friction factor and convective heat transfer coefficient showed an increase with increasing particle volumetric concentration of the nanofluids. Goudarzi and jamali [10] conducted an experimental study of heat transfer enhancement of Al_2O_3-EG nanofluid in a car radiator with wire coil inserts. Two wire coils inserts with different geometry and nanofluids with volume concentrations of 0.08%, 0.5% and 1% were investigated. Their results indicated that the use of coils inserts enhanced heat transfer rates up to 9%. In addition, the simultaneous use of the coils inserts with the nanofluid with concentration of 0.08%, 0.5% and 1% vol resulted the thermal performance enhancement up to 5% as compared to the use of coils inserts alone.

Most studies have been concerned with passive methods. Recent interests in the use of nanofluids [11] for possible heat transfer intensification have attracted the attention of many investigators. Also some researchers have focused on improving heat transfer by electric field [12-13]. So far only Vithayasai et al. [14] conducted an experimental research on the effects of the electric field on the car radiator heat transfer performance when the air speed of the front radiator is low. Their results showed that the unit with electric field pronounced better heat transfer rate, especially at low frontal velocity of air.

Above literature review show that so far many studies are reported for heat transfer enhancement in car radiators using nanofluids. But, few studies are done about the effect of electric field on heat transfer in car radiator. In the other word, simultaneous effects of nanofluids and electric field on thermal performance of car radiator are not investigated. Hence, the aim of the present study is to study the heat transfer coefficient in the turbulent flow of Al_2O_3/PW nanofluid in car radiator with and without electric field.

2. Experimental setup and description Al_2O_3

2.1 Experimental setup

The experimental setup is shown in Figure 1. Also, the experimental setup is shown schematically in Figure 2.

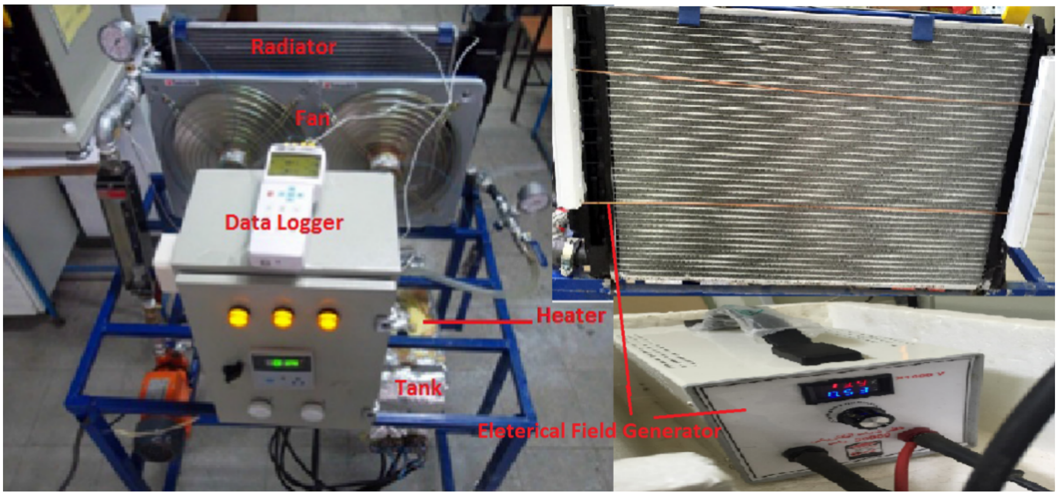

Figure 1. The experimental setup

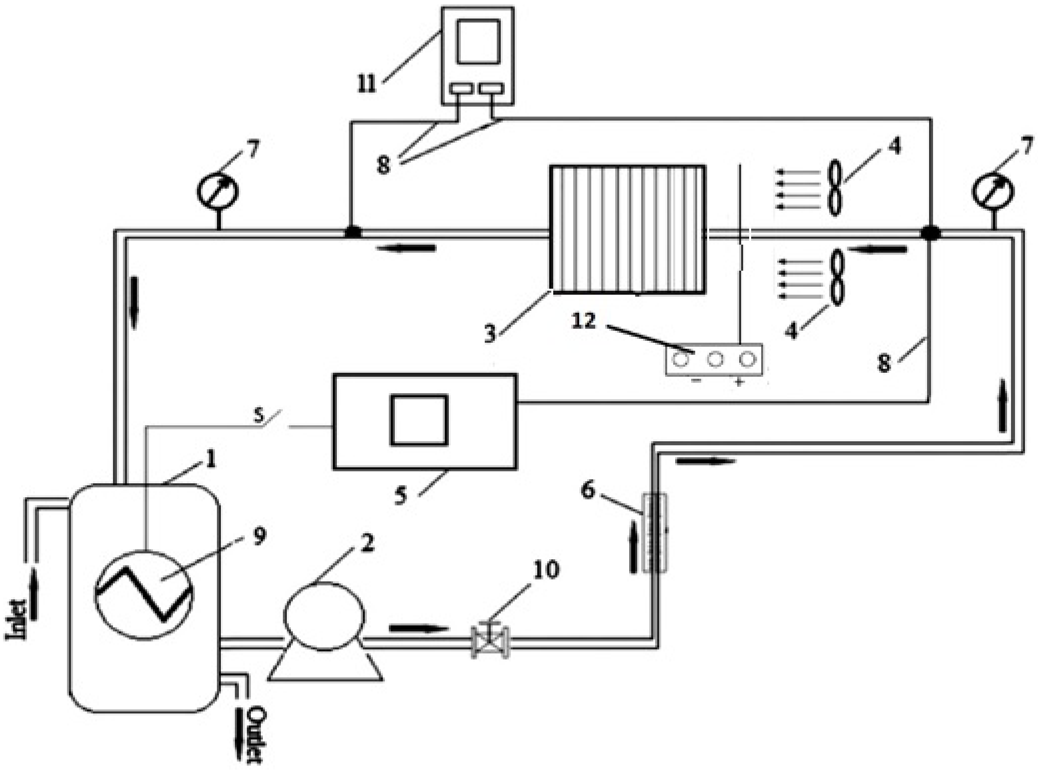

Figure 2. Schematic of the experimental apparatus; (1) tank, (2) pump, (3) radiator, (4) fan, (5) controller device, (6) rotameter, (7) pressure gauge, (8) thermocouple, (9) elements, (10) line valve, (11) data logger, (12) electric field generator

This experimental setup includes:

(1) Tank: the reservoir has a capacity of about 18 L of cooling fluid that the coolant is placed in it. 6 heat electrical elements used in the tank to raise the temperature of the coolant fluid, similar to engine temperature rises during operation, which is about 80 °C. (2) Pump: a pump with Diamond QB-60 model used, which has a Qmax=35 lit/min, Hmax=35 m, 0.5 hp power and its speed is around 2850 rpm. This pump is one step and using a tap placed on the pump output can be different to the flow rate adjusted. (3) Radiator: the radiator used in this paper belongs to the Peugeot 405 vehicle. This radiator is a compact heat exchanger which contains 40 channels with dimensions of 24 ⁄ 1.5 mm. (4) Fan: According to the vehicle structure (Peugeot 405) fans are used behind the radiator. The fan with C78/22/4SO model and with specifications PH:1, HZ:50. V: 220 used. Fan speed is adjustable in the trial of three low, medium and high. (5) Controller device: This

device contains fuses regarding a thermal element and pump, digital displayer, temperature sensor connected to the radiator inlet and screws to adjust fan speed. By the fluid inlet temperature to the radiator temperature sensor shows and according to the desired temperature of the fluid control device is set on it, electric heating elements off, and if the temperature is set lower, connected. Digital displayer shows the inlet temperature of the fluid to the radiator. (6) Rotameter: Flowmeter used in this study is rotameter with LIQID-SP.GR.1.O model. This flowmeter installed at the entrance to the radiator. (7) Pressure gauges: In the experimental setup, two pressure gauges with EN-837-3 models in the pressure range from 0 to 160 mbar are used. They installed at the input and output of radiator. (8) Thermocouples: five thermocouples (type K) are used to measure the fluid temperature in the input and output of radiator. Other thermocouples are used for measuring the temperature on the radiator body wall. By connecting all the thermocouple to the data logger, temperature measured and recorded. (9) electrical field generator: High Voltage Power Supply to generate an electric field with a capacity of 30 kV. It installed in the front of radiator.

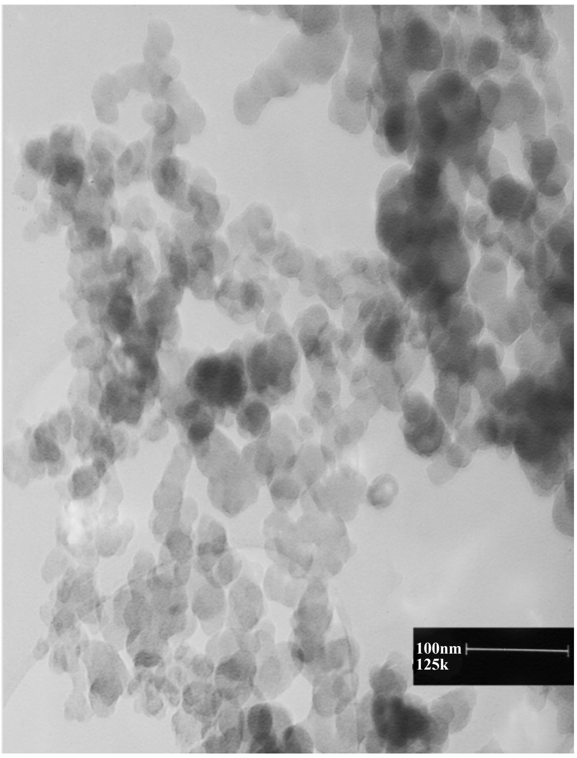

Figure 3. SEM photograph Al_2O_3 particle

2.2 Nanofluids preparation

In this study, Al_2O_3 nanoparticles with an average size of 20 nm are used. Pure water (PW) is used as the base fluid. A small quantity of sodium dodecylbenzene sulfonate (SDBS) is used as dispersant (24 gr). There are three techniques for the preparation of nano-fluids with the final stability of dispersions [15]; (1) changing the pH value of suspensions; (2) adding the surface activators to the suspensions; (3) putting in an ultrasonic apparatus. In this study, ultrasonic apparatus is used for the preparation of nano-fluid. The first stage is to mix nanoparticles in pure water and the second stage is to homogenize the mixture using ultrasonic vibration (UP-400S model), which is showed in Figure 4 with working frequency of 24 kHz and useful output power of 400 W. After sonification for approximately 45 minutes, the dispersion of the nanoparticles is established by visual observation for nanoparticle sedimentation. Since the sonication time is an important factor for breaking down agglomerates, uniform dispersion and stable suspension of nanoparticles in liquid this time was selected 30 min after several tests. In present work, nanofluid with three volume concentrations contains (0.08%, 0.5% and 1% vol.) are used. The physical properties of nanoparticles are listed in Table 1. The SEM (scanning electron microscope) micrograph of the prepared sample is shown in Figure 3.

Table 1. The specifications of the used nanoparticles in the current study [10]

Density (kg/m3)	Thermal conductivity (W/m K)	Heat capacity (J/kg K)	Color	Morphology	Diameter (nm)	Purity (%)	Nano fluid
3890	40	880	white	Nearly spherical	20	99	Al_2O_3

2.3 Electric field generation

In this work, a set of electrodes is fixed in front of the car radiator. The electrode positions are shown in Figure 4. The voltage of the electric field is controlled by a high voltage generator and in this study it is varied from 0 to 20 kV.

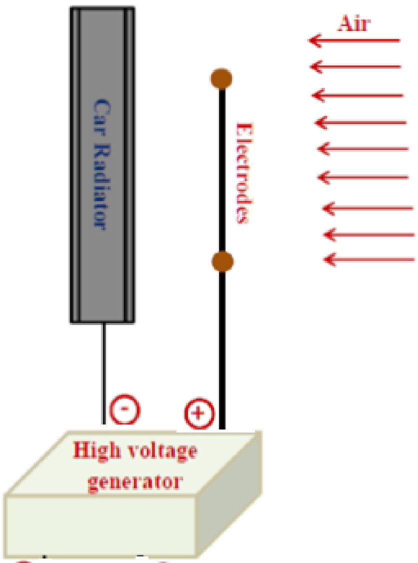

Figure 4. The arrangement of electrodes and high voltage generator

3. Results and discussion

In this study, by measuring the temperature and pressure in certain areas such as, input and output radiator, radiator wall temperature and ambient temperature at different flow rate; the heat transfer coefficient and thermal performance factor are determined. Also, the effect of parameters such as mass flow rate, fan speed, electric field voltage and concentration of the nano-fluid studied.

The friction factor is obtained from the Eq.(1);

$$f = \frac{D_H}{L}\left(\frac{2\Delta P}{\rho U^2}\right) \quad (1)$$

where ΔP is the pressure difference between the inlet fluid and outlet fluid in the radiator. D_H, is hydraulic diameter in the radiator channel, which of the following equation is obtained [16].

$$D_H = \left(\frac{4V}{\pi L}\right)^{0.5} \quad (2)$$

where V and L are the volume and height of the radiator, respectively, where V is obtained from the Eq. (3).

$$V = 40\, A \bullet W \quad (3)$$

where A and W are cross-sectional area pipe and length of the radiator, respectively.

Also, Mean flow velocity in the radiator is calculated from the continuum equation.

$$U = \frac{\dot{m}}{\rho A} \tag{4}$$

where $\dot{m}$ is mass flow rate in radiator and measured with rotameter.

The heat transfer coefficient and corresponding Nusselt number can be derived as follows:

The heat transfer rates due to the fluid flowing inside the tube to the outside air flowing in the air flow can be calculated as:

$$Q_{f1} = \dot{m} C_{p.nf} (T_i - T_o) \tag{5}$$

$$Q_{f2} = h A_s (\tilde{T}_w - T_b) \tag{6}$$

where Q_{f1} and Q_{f2} are the heat transfer rates for the radiator using two different calculation methods. $\dot{m}$ is mass flow rate. A_s, is the surface area of the radiator. T_b is bulk temperature which is assumed to be the average values of inlet (T_i) and outlet (T_o) temperatures of the fluid moving through the radiator, and $\tilde{T}_w$ is tube wall temperature which is the mean value measured by 3 thermocouples.

Reynolds number is calculated by Eq. (7) to determine the flow regime.

$$Re = \frac{\rho U D_H}{\mu} \tag{7}$$

Then, the heat transfer coefficient and corresponding Nusselt number is obtained from eq's (8) and (9).

$$h = \frac{\dot{m} C_p (T_i - T_o)}{A_s (\tilde{T}_w - T_b)} \tag{8}$$

$$Nu = \frac{h D_H}{k} \tag{9}$$

where k is fluid thermal conductivity. When nanofluid is used as the working fluid in cooling system, k_{nf} is calculated by [15]:

$$\frac{k_{nf}}{k_w} = \frac{k_{np} + 2k_w + 2\varnothing (k_{np} - k_w)}{k_{np} + 2k_w - \varnothing (k_{np} - k_w)} \tag{10}$$

Where $\varnothing$ suggests the volume fraction of nanoparticles.

$C_{p.nf}$ and ρ_{nf} are the heat capacity and density of nanofluid respectively that can be calculated by Eqs. (11) and (12) [15]:

$$C_{p.nf} = \frac{\varnothing \rho_{np} C_{p.np} + (1 - \varnothing) \rho_w C_{p.w}}{\rho_{nf}} \tag{11}$$

$$\rho_{nf} = (1 - \varnothing) \rho_w + \varnothing \rho_{np} \tag{12}$$

Also, Viscosity of nanofluids was calculated with Eq. (13) [16].

$$\mu_{nf} = \mu_w (1 + \eta \varnothing) . \eta \tag{13}$$

where η =2 • 5, as recommended for hard spheres [16].

The thermal performance factor of the radiator with coil wire inserts under same pumping power criteria is given by [1];

$$\eta = \frac{Nu_{nano} + _{ehd}}{Nu_{purewater}} \quad (14)$$

Where $Nu_{nano+ehd}$ and $Nu_{purewater}$ are the Nusselt number for the radiator with nanofluid and electric field and Nusselt number for the radiator without nanofluid and electric field, respectively.

In this study, from Al_2O_3 nanoparticles to improve the thermal properties of the base fluid (pure water) used. These experiments in three flow rate of 8, 11 and 14 lit/min and the Reynolds number in the range of $2900 < Re < 3400$ and three fan speed 0, 600 and 1200(rpm) are investigated. Therefore, in present work the effect of electric field in three voltages 8, 11 and 14 kV with nanofluid in volume concentrations 0.08, 0.5 and 1% are investigated.

Also, to validate the results the comparison was made between the experimental data and empirical correlations developed by Pack-Choy [17].

$$Nu_{nf}=0.021Re_{nf}^{0.8}Pr_{nf}^{0.5} \quad (15)$$

where Re_{nf} is Reynolds number of nanofluid and Pr_{nf} is Prandtl number of nanofluid.

Nusselt number of nanofluid in radiator with different volume concentration for the different speed is shown in Figure 5. The experimental results clearly show that the Nusselt number increased by increasing the fan speed Also, In Figure 6 good agreement can be seen between empirical correlations and the results obtained in this study.

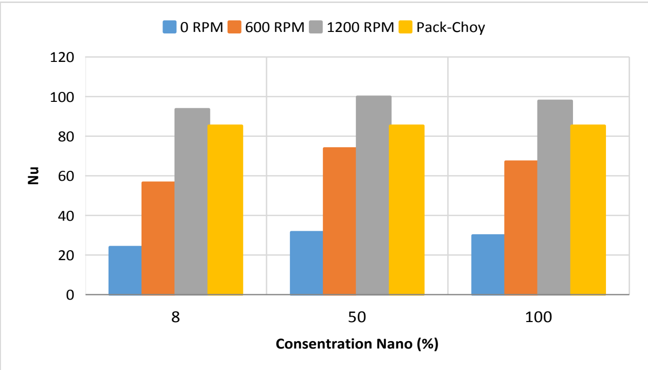

Figure 5. Effect of Al_2O_3/PW nanofluid volume concentration on Nusselt number for the different speed

Figure 6 shows the Nusselt number of the nanofluid in radiator at Re = 2677 for the different fan speed in the range of $0 < N < 1200$. In all cases, Nusselt number increased with increasing speed of cooling fan for all concentration. But increasing the nanofluid concentration up to 1% vol., because of instability of nanoparticles causes, the heat transfer coefficient at 1% vol be less than 0.5% vol. The minimum and maximum change in Nusslet number by fan speed are 7% at N = 1200 (approx.) and 95% at N = 600 (approx.), respectively.

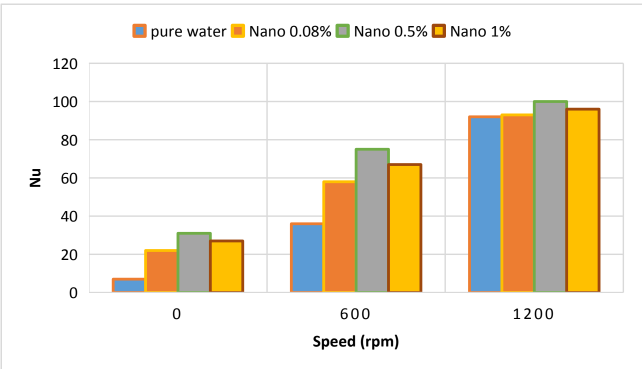

Figure 6. Nusselt number of nano-fluidAl_2O_3/PW with volume concentration for various speeds

Figure 7 shows the Nusselt number of the working fluid in radiator at Re = 2677 for the different fan speed in the range of 0 < N < 1200 for electric field with different voltage. As shown in Figure 8, the Nusselt number increased with increasing the speed of cooling fan for all voltage. The main reasons for this increase are the ability of suspended nanoparticles enhancing thermal conductivity and movement of nanoparticles carrying energy exchange. The largest increase in Nusselt number about 210% is related to the voltage 14 kV at N = 600 (approx.).

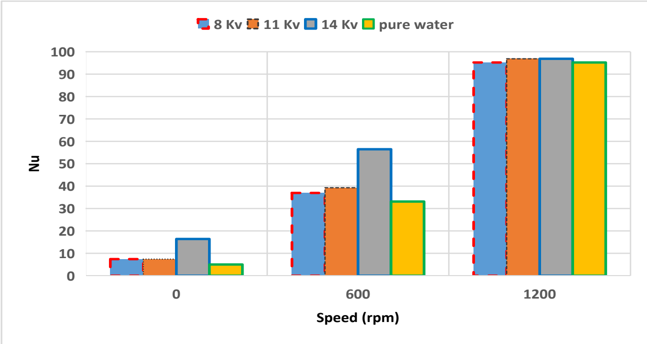

Figure 7. Effect of electric field volume voltage on Nusselt number of nano-fluidAl_2O_3/PW for various speeds

Nusselt number in Figure 7 shows that the electric field at 8, 11 and 14 kV enhanced heat transfer by 112%, 119% and 171%, respectively, compared to that of pure water as base fluid at Re = 2677.

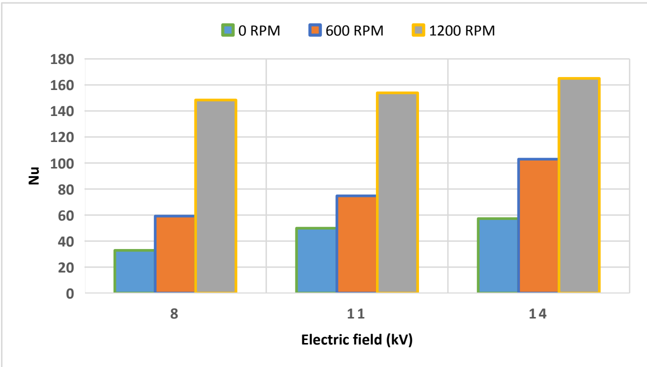

Figure 8. Nusselt number of nano-fluid with concentration of 1% and electric field for various voltages

Figure 8 shows the effect of electric field on Nusselt number of Al_2O_3/PW nanofluid the radiator for the different fan speed in the range of 0 < N < 1200. The results show that the Nusselt number increased with increasing the voltage of electric field. Translation errorFor example, when the fan is off and the electric field voltage is 8 kV, Nusselt number at 1% vol. is about 32.87 and 0.55 times smaller than 600 rpm and 0.22 times smaller than 1200 rpm. When the electric field voltage is 8 kV, Nusselt number at is about 165.03 that is 1.6 times greater than 600 rpm and 2.8 times greater than 0 rpm. Also, for all electric field Nusselt number increased with increasing the fan speed.

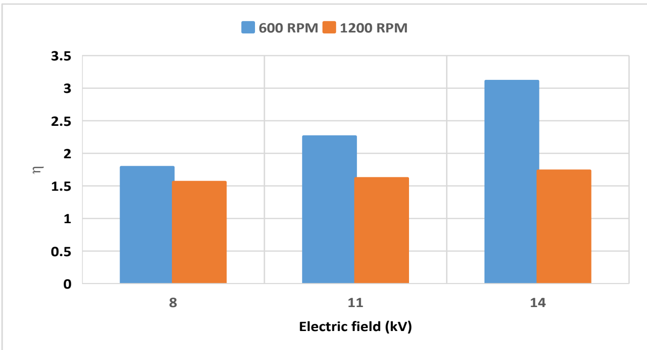

Figure 9. Thermal performance factor Vs voltage for nano-fluid with concentration of 1% and electric field for the different fan speed with

The thermal performance factor for all fan speed with different voltage is shown in Figure 9. With the use of nanofluid with concentration of 1% and electric field for fan speed 600 and 1200 rpm, thermal performance factors were in a range between, 1.8-3.2 and 1.6-1.74, respectively. The results show that the values of thermal performance factor are significantly different for different cases. On the other hand, thermal performance factor is more than 1 in all of cases, and it can be concluded that this technique can be used in car radiators to improve heat transfer. This is due to variation of temperature provided, higher thermal conductivity.

4. Conclusions

Experimental studies of heat transfer enhancement of car radiator with electric field and Al_2O_3 nanofluid have been presented. The electric field with different voltage and Al_2O_3 nanofluid with different volume concentration were investigated. The conclusion can be drawn as follows:

1. Nusselt number at Reynolds number of Re=2677 for the different fan speed in the range of $0 < N < 1200$ with electric field (8, 11 and 14 kV) is higher compared to pure water without electric field. The degree of heat transfer enhancement depends on the value of the voltage supplied.

2. Nusselt number at Reynolds number in the range of Re=2677 for the different fan speed in the range of $0 < N < 1200$ with nanofluids with the volume concentrations of 0.08%, 0.5% and 1% is higher when compared to pure water as base fluid.

3. The electric field can enhance the heat transfer rate of the automobile radiator especially at low fan speed. When the fan speed is over 1200 rpm, the electric field does not show a significant effect on the thermal performance.

4. Nusselt number at Re=2677 with the volume concentrations of 0.08%, 0.5% and 1% and electric field with different voltage for the different fan speed in the range of $0 < N < 1200$ increased with increasing speed of cooling fan.

5. There is significant difference in thermal performance factor at the different elevtric field. In all of cases, thermal performance factor is more than 1, and can be concluded that this technique can be used in car radiators to improve heat transfer.

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