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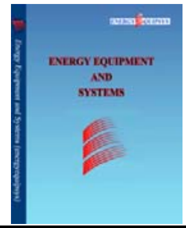

Thermal performance enhancement of automobile radiator using water-CuO nanofluid: an experimental study

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ABSTRACT

In the present paper, the effect of water-CuO nanofluid on the radiator heat transfer of an automobile, Peugeot 405 XU7 engine type is investigated experimentally. The experiments are carried out for the radiator water (water-ethylene glycol with a volume fraction of 80-20, respectively) as a base fluid and water-CuO nanofluid with the volume fraction of 0.5% and 1%. Sodium Dodecyl Sulfate (SDS) is used to increase the stability of nanofluid. The results demonstrated that a significant increase in the heat transfer of the engine to the environment is obtained by adding CuO nanoparticles to the base fluid. For nanofluid volume fraction of 0.5 and 1% for a mass flow rate of 30 liters per minute, the heat transfer rate enhances 3% and 6.9%, respectively, in comparison with the base fluid. Although convective heat transfer coefficient increased by increasing the nanofluid volume fraction, the experiments showed that this coefficient increases with the mass flow rate up to 20 liters per minute and then decreases with the mass flow rate. Besides, the radiator pressure drop increases by increasing of the pressure of nanofluid. The results revealed that the ratio of heat transfer and pump power (merit parameter) decreases as the nanofluid pressure increases.

Keywords: Car Engine, Heat Transfer, Radiator, Water-CuO Nanofluid.

1. Introduction

The heat transfer rate of nonmetallic fluids is much lower than that of metallic ones due to their lower thermal conductivity. Several methods are used to increase the heat transfer rate of these fluids. One of these methods is to use equipment such as a heat exchanger. A heat exchanger aims to recover heat from hot stream and reduce the heat transfer surface area for a given thermal capacity. The radiator is the most important heat exchanger in an automobile. If the appropriate fluid in the radiator can transfer heat at a high speed, the radiator is designed in smaller dimensions and allows aerodynamics to be designed for the vehicle. In addition, there is no need for a large fluid flow rate to increase heat transfer. On the other hand, coolant fluid pump can be made smaller and consume less energy. Adding nanoparticles to the working fluid leads to a significant increase in the thermal conductivity of the fluid. In recent years, applied researchers have become interested in thermal systems, microelectronics, motor oil and lubricants. The cooling fluid that is used in the cooling system of an automobile is usually made up of water and ethylene

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glycol. The idea of adding solid particles in liquids was first introduced by Maxwell [1]. Choi and Eastman [2] and Masuda et al. [3] were the first researchers that suggested the use of nanoparticles in the modern sense. Lee et al. [4] obtained thermal conductivity of different nanoparticles, such as Al_2O_3-water, Al_2O_3-Eg, CuO-water and CuO-Eg, using hot-wire transfer method. Their results showed that thermal conductivity is a function of the size, shape of the particle, and the thermophysical properties of the base fluid and nanoparticles. Singh et al. [5] examined the effect of using nanoparticles in vehicle radiators. According to their studies, the use of nanofluids instead of water can reduce the radiator heat exchanger up to 10% results in better aerodynamics and a reduction in fuel consumption up to 5%. On the other hand, the nanofluid flow from the radiator channel causes erosion and corrosion. This was illustrated by examining the reduced weight of the radiator as a function of fluid velocity and the angle of the collision. Saripella et al. [6] examined numerically the effect of CuO-water-ethylene glycol nanofluid (50:50) with volume fractions of 2% and 4% in a radiator of a truck. Their results showed 40% and 5% increase in the Nusselt number and engine power, respectively. Also, the radiator's surface and fuel consumption decrease 5% and 2.5%, respectively. Putra and Maulana [7] investigated the effect of water-Al2O3 nanofluids with volume fractions of 1% and 4% in an automobile radiator. Their results showed an increase of 31% to 48% in convective heat transfer coefficient for the volume fraction of 1% and an increase of 52% to 79% for the volume fraction of 4%. Vasu et al. [8] studied the thermal performance and pressure drop of a sample radiator for water, water-ethylene glycol (50:50) and water-alumina nanofluid with volume fractions of 1%-4% numerically and showed that cooling capacity, total heat transfer coefficient and cooling pressure drop for water-alumina nanofluid with a volume fraction of 4% are 38.7%, 74%, and 110.3%, respectively, in comparison with pure water. They found that cooling capacity for water-alumina nanofluid with a volume fraction of 4% has an enhancement between 46.8%-89.5% in comparison with a water-ethylene glycol mixture (50:50). Vajjha et al. [9] examined the heat transfer of laminar nanofluid flow in a radiator tube for a Reynolds number of 100 to 2000 at inlet coolant fluid temperature of 90 ° C and a constant heat transfer coefficient of 50 W/m^2K numerically. They found that adding aluminum oxide nanoparticles with volume fraction of 10% and copper oxide nanoparticles with volume fraction of 6% leads to 91% and 86% in convective heat transfer coefficient, respectively.

Sheikhzadeh et al. [10] examined ethylene glycol-copper nanofluid with volume fractions of 0-5% in a radiator. Their results showed an increase of 63.4% in the heat transfer coefficient at the volume fraction of 5%. They showed a decrease in the coolant flow temperature from 86.8°C to 78.7 °C for inlet air temperature of 20 ℃ and a reduction in the coolant outlet temperature from 89.6 °C to 85.2 °C for inlet air temperature of 50 ℃.

Peyghambarzadeh et al. [11] investigated the heat transfer in an automobile radiator using water-Al2O3 nanofluid. The volume fraction of nanoparticles was 0.1%-1%. The highest percent increase in heat transfer was 45% for the volume fraction of 1%.

Xie et al. [12] reported an increase in heat transfer using oxide of aluminum, tin, titanium, and magnesium in a mixture of water-ethylene glycol (55%-45%). Aluminum oxide, magnesium oxide, and tin oxide nanoparticles had a higher heat transfer compared to titanium oxide nanoparticles.

Peyghambarzadeh et al. [13] studied the heat transfer of an automobile radiator using copper oxide and iron oxide nanoparticles with water as a base fluid at three-volume fractions of 0.15%, 0.4%, and 0.65%. The Reynolds number varied from 50 to 1000 and the cooling input temperature varied from 50 to 80°C. Both nanofluids showed a 9% increase in total heat transfer coefficient in comparison with the pure water. The increase in the input temperature of the nanofluids results in a reduction in overall heat transfer coefficient.

Hussein et al. [14] used water-titanium oxide and water-silicon oxide nanofluids in a radiator. The volume fraction and inlet temperature of nanofluids varied between 1.0%-3.0% and 60°C -80°C. They showed that heat transfer rate increases 11% and 22.5% using nanoparticles of titanium oxide and silicon oxide, respectively.

Naraki et al. [15] experimentally investigated the laminar flow of CuO-water nanofluid in an automobile radiator. The volume fraction was in the range of zero to 0.4% and the input temperature varied from 50°C to 80°C. An 8% increase in total heat transfer coefficient was reported in comparison with pure water for the case of 0.4% nanofluid volume fraction.

Hafiz et al. [16] investigated the effect of ZnO-water nanofluid on heat transfer of a radiator with different volume fractions. They demonstrated that the volume fraction of 0.2% leads to 46% increase in heat transfer. It was also shown that the heat transfer rate decreases for the volume fraction above 0.2%. Sheikhzadeh and Fakhary [17] studied the heat transfer in a flat tube of a radiator of an automobile using alumina-water/ethylene glycol (60:40) nanofluid. They examined several relationships related to the calculation of the Nusselt number in the presence of the nanofluid. Samira et al. [18] experimentally studied the effect of CuO/ethylene glycol (60%)-water (40%) nanofluid on the thermal performance of an automobile radiator. They performed experiments with various nanofluid volume fractions and showed that heat transfer increases with the volume fraction.

Nomenclature

ρ	Density, *kg/m*^{3}
C_p	Specific heat capacity,J/kg K
k	Thermal conductivity, W/mK
h	Convective heat transfer coefficient, *W/m*^{2} *K*
A	Heat transfer area, *m*^{2}
L	Tube length, m
P	Wetted perimeter, m
d_{hy}	Hydraulic diameter, m
T_b	Bulk temperature, K
T_{in}	Inlet temperature, K
T_{out}	Outlet temperature, K
T_w	Wall temperature, K
$\dot{m}$	Mass flow rate, *kg/s*
Nu	Nusselt number
Re	Reynolds number
Me	Merit parameter
p	Pressure, Pa
pr	Prandtl number
Q	Volumetric flow rate, lit/min
q	Heat transfer rate, W

2. Governing equations

The thermophysical properties of nanoparticles at different temperatures and various concentrations are evaluated using some classical formulas commonly used for two-phase flows [23, 24]. In these relationships, φ is the volume fraction of nanoparticles added to the base fluid. The subscripts *bf*, *nf*, and p indicate the base fluid, nanofluid and nanoparticles, respectively. The density of the nanofluid is calculated by the equation of Pak and Cho [19]:

$$(\rho_{\mathrm{nf}}) = (1-\phi)\rho_{\mathrm{bf}} + \phi\rho_{\mathrm{p}} \quad (1)$$

To determine the specific heat capacity of the nanofluid, the relation proposed by Pak and Cho [20] is used:

$$C_{P_{nf}} = (1-\phi)C_{P_{bf}} + \phi C_{P_p} \quad (2)$$

The following relation is Einstein's relation that determines the viscosity of nanofluid as a linear function of the volume fraction [20]:

$$\mu_{nf} = \mu_{bf}(1+2.5\phi) \quad (3)$$

The Hamilton-Croseer model is used to determine the thermal conductivity of the nanofluid [21]:

$$K_{nf} = \left[\frac{\mathrm{K_p} + (n-1)\mathrm{K_{bf}} - \phi(\mathrm{n}-1)(\mathrm{K_{bf}} - \mathrm{K_p})}{\mathrm{K_p} + (n-1)\mathrm{K_{bf}} + \phi(\mathrm{K_{bf}} - \mathrm{K_p})}\right] \times \mathrm{K}_{bf} \quad (4)$$

where, k is thermal conductivity and n is shape factor, n = 3/ψ. Ψ = 1, 0.5 for spherical and cylindrical particles, respectively. Two parameters that are used to determine the thermal performance of a system are the convective heat transfer coefficient and the Nusselt number. The heat transfer coefficient is defined as [22]:

$$h=\frac{q}{A\Delta T_b} \quad (5)$$

where, q is the heat transfer from the fluid along the duct, A is the wall area and ΔT_b is the difference between the wall temperature and the bulk temperature. q can be obtained as follows:

$$q=\dot{m}C_{P_{nf}}(T_{in}-T_{out}) \quad (6)$$

The bulk temperature,T_b is defined as the average fluid temperature of the inlet and outlet of the radiator:

$$T_b=\frac{T_{in}+T_{out}}{2} \quad (7)$$

where, T_W is the wall temperature of the tube. $T_{in}$and $T_{out}$are the fluid temperatures at the inlet and outlet of the heat exchanger, respectively. Hence, the convective heat transfer coefficient is defined as:

$$h=\frac{\dot{m}C_{P_{nf}}(T_{in}-T_{out})}{A(T_b-T_w)} \quad (8)$$

The Nusselt number is calculated as follows:

$$Nu_{nf}=\frac{hD}{K_{nf}} \quad (9)$$

The volume fraction of nanofluid is obtained by the following relation:

$$\varphi=\left[\frac{\frac{w_p}{\rho_p}}{\frac{w_p}{\rho_p}+\frac{w_{bf}}{\rho_{bf}}}\right]\times 100 \quad (10)$$

where wp is the weight of the nanoparticle and wbf is the weight of the base fluid.

3. Experimental setup

3.1. Engine

Peugeot 405 XU7 engine type with a complete cooling system that is capable of being lit and settled on a base. This engine has a volume of 1761 cc. The four-cylinder engine has a compression ratio of 9.25:1 and produces a power of 97 horsepower at 6000 RPM and a maximum torque of 148 N/m at 3500 RPM. It has 8 valves and has a standard Euro II emission limit value. Catalyst PGM20 is used to limit exhaust pollution. The volume of oil consumed is 4.4 liters (4.75 liters if a filter is used). The volume of water and coolant is 6.6 liters. The technical information for this engine is shown in Table (1).

3.2. Cooling system of XU7 engine

In this research study, the cooling system of the XU7 engine is studied. The cooling system of this engine is a closed-circuit with an electric fan that is shown in Fig. 1. The details of the cooling system is presented in Table 2.

The radiator shown in Fig. 2 has been made of aluminum. It is of a horizontal type, so the working fluid flows inside the horizontal radiator from the right to the left.

Table 1. Peugeot 405 XU7 engine type specification

Engine type	4-cylinder in-line
Piston diameter, mm	83
Piston stroke, mm	81.4
Engine capacity, cc	1761
Compression ratio	9.25:1
Maximum power, hp	100@6000 RPM
Maximum torque, Nm	153@3500 RPM
Fuel system	Multi-point injection
Fuel type	Unleaded petrol

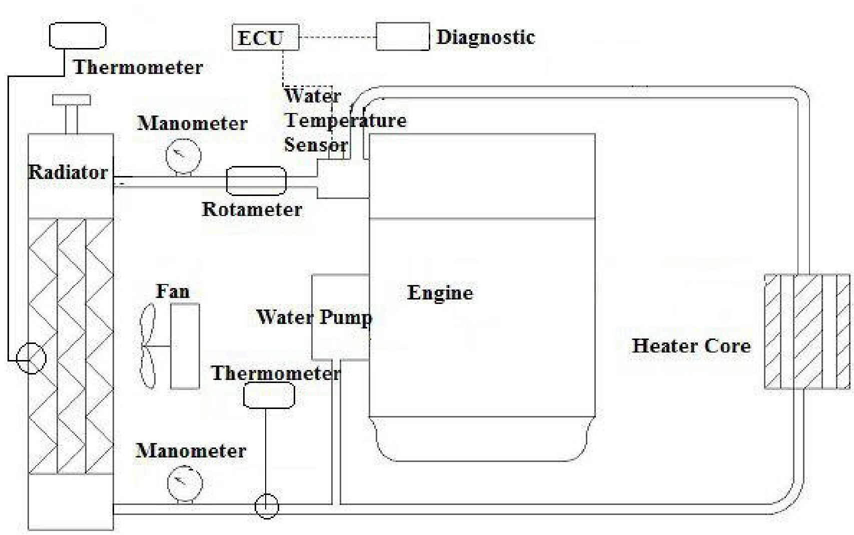

Fig 1. Schematic of the cooling system of XU7 engine

Table 2. The details of the cooling system of XU7 engine

Capacity, liter	6.6
System pressure, bar	1.4
Thermostat opening temperature, ℃	88
Temperature warning light, ℃	118
Fan starting temperature (first stage), ℃	94
Fan starting temperature (second stage), ℃	102

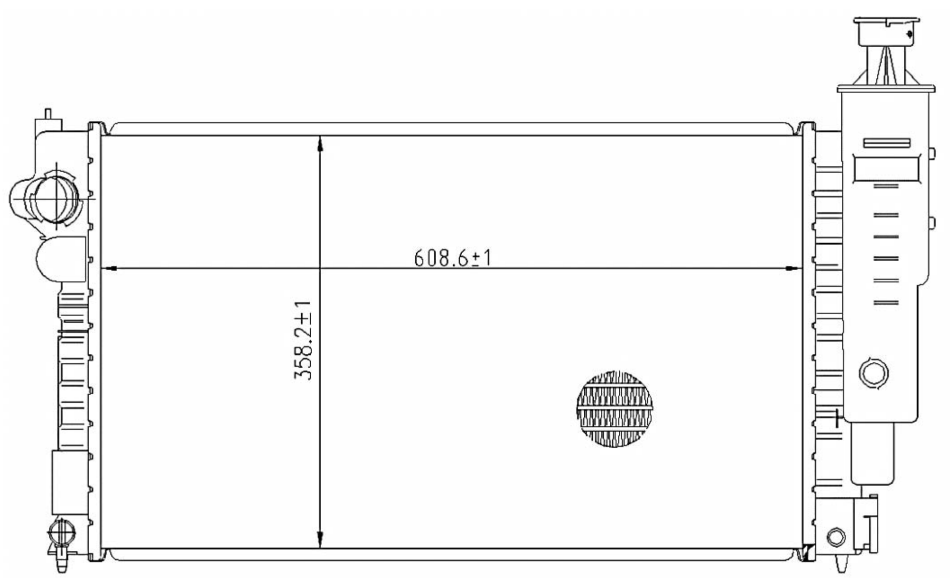

Fig 2. Schematic of the radiator

The radiator has 39 horizontal pipes with a length of 63 cm and an elliptic cross-section with diameters of 24.5 and 1.7 mm (see Fig.3). More detailed information on the geometry of this radiator is given in Table (3).

The cross-section of a radiator tube (Fig. 4) is:

$$A_b = a.b + \frac{\pi}{4}b^2 = 22.8 \times 1.7 + \frac{\pi}{4}(1.7)^2 = 41.028\, mm^2$$

Also, the circumference of the tube is equal to:

$$P = 2a + \pi b = 22.8 \times 2 + (1.7)\pi = 50.938\, mm$$

Since the number of radiator tubes is 39 and its length is 630 mm, the radiator heat exchanger area is equal to:

$$A = P \times l \times N = 50.938\ * 39 * 630 = 1251546.66\, mm^2$$

Also, the hydraulic diameter of the tube is calculated:

$$d_{hy} = \frac{4A_b}{p} = 3.222\, mm$$

Two fans are used for cooling the radiator (Fig. 2). These fans work with a 12V DC battery and turn slow or fast. If the engine water temperature reaches 94□C, the fans are placed in a series circuit by the ECU unit so that the voltage will be halved. When the temperature reaches 102°C, the fans are placed in a parallel circuit. In the present experiment, a key is used to control the rotation of the fans.

The water temperature sensor is used to bring the engine water temperature information to the ECU unit. This feature, referred to as the variable resistor with temperature (Thermistor), is the resistance that increases or decreases with the temperature variation. The water temperature sensor for this engine is NTC. In this type of sensor, the temperature change causes a decrease in internal resistance. The internal resistance of this sensor indicates the engine water temperature.

The TM-914C digital thermometer is used for measuring the output water temperature and radiator body with a precision of 0.1°C. Also, a rotameter is used to measure the volumetric air flow rate. In the present experiment, a linear rotameter is used. This is a LZT-2520G rotameter with a measurement range of 2-20 GPM (7.566-75.66 LPM) and accuracy of ± 4%. Also, the rotameter is mounted perpendicular to the water pipe.

Two barometers (0-60 psi) are used to measure the fluid pressure drop inside the radiator, with a precision 0.25 psi. The barometers are installed at the inlet and outlet of the radiator.

A diagnostic tool is used in spark-ignition engines to determine the cause of the engine problem. The water temperature and engine rpm are measured by diagnostic device.

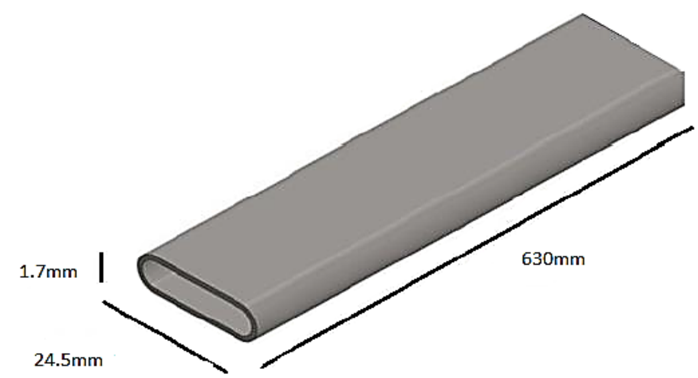

Fig 3. Schematic of a radiator tube

Table 3. Detailed information of the radiator

Fin and tube material	Hydraulic diameter	Fin thickness	Number of tubes	Distance between fins	Distance between tubes
Aluminum	3.222 mm	0.02 mm	39	2.16 mm	8 mm

3.3 Nanofluid

Since nanoparticles tend to form a mass due to strong Van der Waals forces, the preparation of a homogeneous suspension with high stability is one of the biggest challenges in working with nanofluids. Most researchers use ultrasonic agitation, the addition of surfactants, and PH adjustment in order to stabilize the distribution of nanoparticles in the base fluid. In the ultrasonic agitation, the duration of wave propagation is one of the most important parameters. In some studies, long-wave excitement was caused phenomena such as the separation of phases and the formation of the foam layer on the fluid surface [23]. In some studies, optimal wave duration has been reported. Ghadimi and Metselaar [24] studied the effect of ultrasonic processing on the stability of titanium nanofluid and reported the duration of three hours as the optimal time of ultrasonic process by evaluating the nanofluid absorption. Cole and Dey [25] investigated the effect of prolonged ultrasonication on the thermal conductivity of ZnO/ ethylene glycol nanofluids and measured the duration of 60 hours as the optimal time for ultrasonic process. Several studies have been done to investigate the effect of surfactant concentrations on nanofluid stability [26], but fewer studies have been done on the effect of surfactant type. Wang et al. [27] used polyvinylpyrrolidone to stabilize silver nanoparticles and achieved stability for at least a month. Karthik et al. [28] used NiAl nano-dispersoid on the stability and heat transfer characteristics of water-based nanofluid and stated that a more potent absorption of this material yields greater stability. In this study, Sodium Dodecyl Sulfate (SDS) with a volume fraction of 1% was used as a surfactant to increase the nanofluid stability.

3.4 Preparation of nanofluid

Initially, distilled water is mixed with ethylene glycol (80:20) and then the nanoparticles with a volume fraction of 1% are added to the mixture. After several experiments, the result showed that the nanofluid containing 1% SDS is the most stable. It should be noted that some researchers believe that the use of this material can have a negative effect on the thermal conductivity of nanofluid. Thus, the experiments were done for the volume fractions less than 1%, but it was found that the nanofluid is not stable sufficiently. Also, experiments showed that the use of SDS with a volume fraction higher than 1% leads to less stability of the nanofluid. After mixing, the mixture is stirred 30 minutes by a magnetic stirrer with 800 RPM. Then, the mixture is placed 25 minutes under ultrasonic waves. The optimum time for applying ultrasonic waves has been obtained after various experiments. In the present work, an ultrasonic device with a power of 500 watts and a frequency of 40 kHz is used. Ice is used to prevent the increase of nanofluid temperature during the ultrasonication. The nanofluid remains stable for two weeks. Measured pH of ethylene glycol should be at least 7. In the present experiments, the measured value of pH before and after adding SDS is 8.1 and 8.4, respectively.

Specifications related to the structure of nanoparticles with XRD images is presented in Figure 4. The location and peak intensity is shown in Fig. 4 correspond to the standard ICDD model number 801916, which represents the crystalline structure of CuO nanoparticles. The analysis of CuO nanoparticles is shown in Table 4. Also, physical properties of nanoparticles are presented in Table 5.

Table 4. The analysis of CuO nanoparticles (ppm)

Ba	Cd	Co	Zn	Sr	Ca	K	P	Mg	Fe	Pb	Mn
0.75	2.5	6.4	195	2.3	400	300	300	75	87	90	3.5

Table 5. Physical properties of CuO nanoparticles (ppm)

True density (g/cm3)	density Bulk (g/cm3)	Specific area (m2/g)	size (nm)	Purity (%)	Apparent shape	color
6.4	0.79	20	40	99	spherical	black

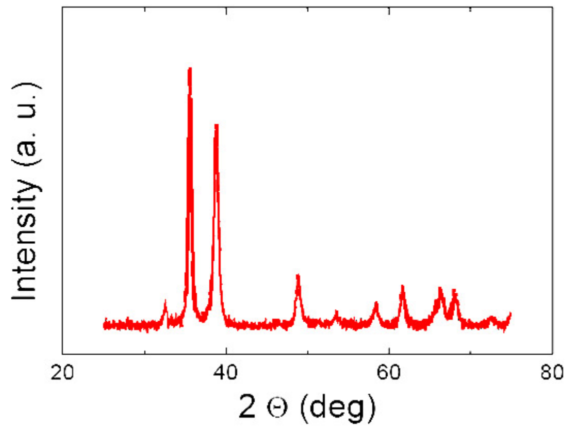

Fig 4. XRD analyze of CuO nanoparticles (40 nm)

First, the engine is checked to find probable technical defects. Then, the circuit of the cooling system is cleaned and control devices are installed. After that, the engine is turned on. The engine speed is set for the specified flow rate until the coolant temperature reaches 85°C. The thermostat opens at this temperature. Considered volumetric flow rates are 12, 20 and 30 liters per minute correspond to 960, 1350 and 1960 RPM. Then the fan is manually run with slow and high speed once the temperature reaches a steady state. The average time in which the system reaches stability is about 6 minutes. But, the results are read and recorded after 12 minutes to ensure that the engine works at steady state. In order to confirm the measurements, the experiments are repeated at similar operating conditions.

In order to carry out experiments, it is first necessary to validate the results and reliability of the laboratory equipment. So, the experiments are done for distilled water for different flow rates and the average Nusselt number is calculated through the relationships introduced in Eq. 9. The present results are validated with the Kays equation [30]:

$$N_u = 3.66 + \frac{0.0668\left({}^{D}/_{L}\right)RePr}{1 + 0.04\left[\left({}^{D}/_{L}\right)RePr\right]^{\frac{2}{3}}} \quad (11)$$

The Nusselt number of present experiments at different Reynolds numbers is compared with the one of Kays equation in Fig. 5. The results show that the experimental results are in good agreement with the Kays relation.

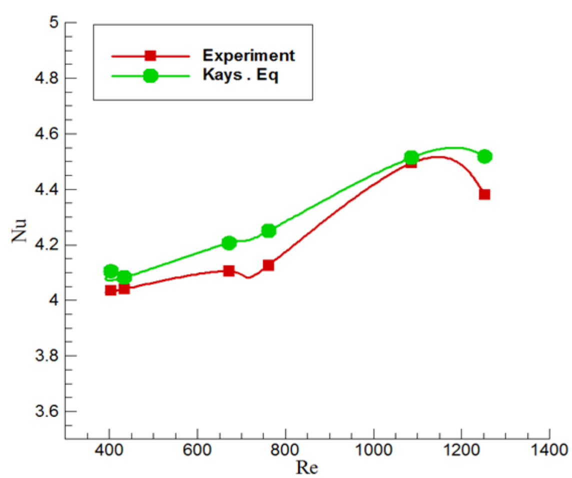

Fig. 5. Nusselt number as a function of Reynolds number: comparison between current experimental results and the results from Kays equation

After validation, the experiments are performed for two nanofluids with volume fractions of 0.5 and 1%. The results are compared with the results of the base fluid of water-ethylene glycol (80:20) at three volumetric flow rates: 12, 20, and 30 liters per minutes. The results of temperature and pressure are recorded from the moment when the fluid inlet temperature reaches the radiator to the thermostat opening temperature of 85°C.

Specific heat capacity and thermal conductivity of water-ethylene glycol (80:20) are as follows, respectively [31, 32]:

$$C_p=0.93576+1.8001\times10^{-4}T$$

$$K=0.28697+6.635\times10^{-4}T-2.9292\times10^{-7}T^2$$

Also, the thermophysical properties of water-ethylene glycol (80:20) at T= 50°C are presented in Table 6. Properties of CuO nanoparticles are presented in Table 7.

4. Results

Convective heat transfer coefficient as a function of volumetric flow rates for the different volume fraction of nanofluid is shown in Fig. 6. It is found that the heat transfer coefficient increases with the volume fraction. It should be noted that convective heat transfer coefficient has a maximum at volumetric flow rate Q = 20 lit/min. Heat transfer coefficient decreases as the flow rate becomes more than 20 lit/min. This is due to an increase in the bulk temperature caused by high engine revolution at high flow rate. The increase of the flow rate is required to increase the engine speed, which causes an increase in the engine heat and a rise in the bulk temperature. The increase in convective heat transfer coefficient at volumetric flow rate of 20 and 3o lit/min is 9.1 and 11%, respectively.

Figure 7 shows the Nusselt number variations with Reynolds number. The Nusselt number reaches its maximum at the Reynolds 400 for a constant volume fraction. Also, as the volume fraction increases, the Nusselt number increases. This is due to the increase in the thermal conductivity of nanofluid. The highest increase in the Nusselt number is 9% corresponds to the Reynolds number of 400 and a volume fraction of 1%.

The amount of heat transfer is shown in Fig 8 in terms of volumetric flow rate. The heat transfer increases by increasing the volume fraction and flow rate. At low Reynolds numbers, the amount of heat transfer of the nanofluid does not significantly increase compared to the base fluid. The increase in the heat transfer of a nanofluid with a volume fractions of 0.5% and 1% is 0.6% and 5%, respectively, for Q = 12 lit/min. Also, for Q = 20 lit/min, the increase in the heat transfer of a nanofluid with a volume fractions of 0.5% and 1% are 1.1% and 5.7%, respectively. In Fig. 9, the heat transfer is plotted as a function of volume fraction. The figure shows that heat transfer at high speed of fan is 33.7% larger than that at low speed for volume fraction of 1%.

Table 6 . The thermophysical properties of water-ethylene glycol (80:20) at T= 50°C [22]

Dynamic viscosity (μ) $(mPa.s)$	Thermal conductivity (k) $(W/m.K)$	Specific heat capacity (C_P) $(J/kg.K)$	Density (ρ) (kg/m^3)
0.947	0.535	3950	1017

Table 7. Properties of CuO nanoparticles [22]

Thermal conductivity (k) $(W/m.K)$	Specific heat capacity (C_P) $(J/kg.K)$	Density (ρ) (kg/m^3)
32.9	550.5	6320

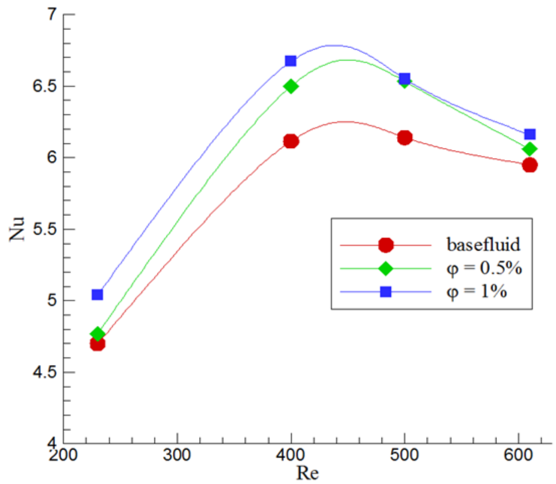

Fig. 7. Nusselt number versus Reynolds number

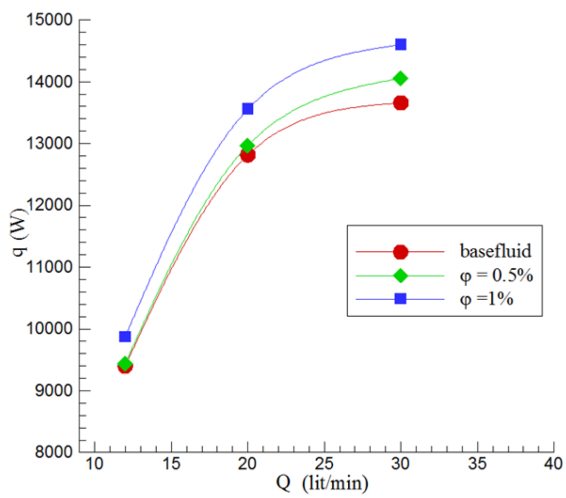

Fig. 8. Heat transfer versus flow rate

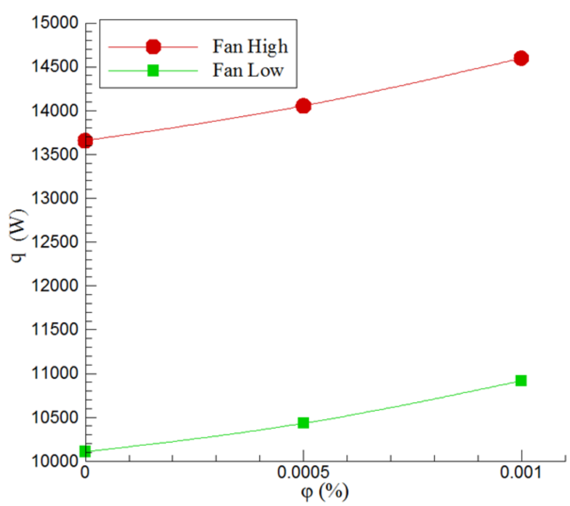

Fig. 9. Heat transfer versus volume fraction of nanofluid for different low and high speeds of fan.

In Fig. 10, the Nusselt number in terms of volumetric flow rate is shown. The Nusselt number increases reaches a maximum at Q = 20 lit/min and then decreases. The decrease is due to the decrease in convective heat transfer coefficient at high flow rates that was mentioned before. Another cause is an increase in the thermal conductivity coefficient because of the increase of bulk temperature. The highest increase in Nusselt number at Q = 20 lit/min corresponds to the volume fraction of 1%.

The convective heat transfer coefficient is shown in Fig. 11 as a function of volume fraction of nanofluid. It is revealed that *h* increases with the volume fraction of nanofluid. The increase in the heat transfer coefficient for a volume fraction of 1% at Q = 12, 20 and 30 lit/min is 8%, 13%, and 11.8%, respectively.

Figure 12 shows the convective heat transfer coefficient in terms of the Reynolds number. It is found that *h* increases by increasing the volume fraction of the nanofluid, reaches a maximum at Re = 450 and then decreases.

In order to measure the pressure drop inside the radiator, two barometers are mounted at the inlet and outlet. The results are shown in Table 8.

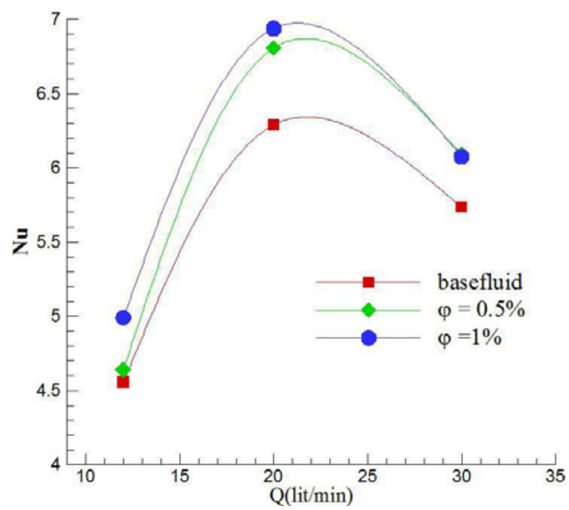

Fig. 10. Nusselt number versus volume fraction

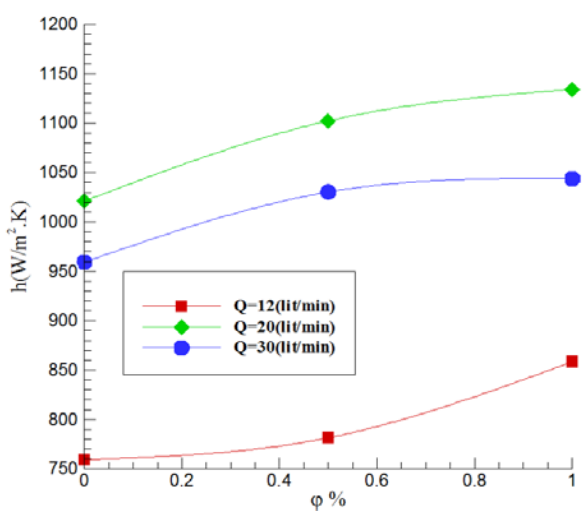

Fig. 11. Convective heat transfer coefficient versus volume fraction

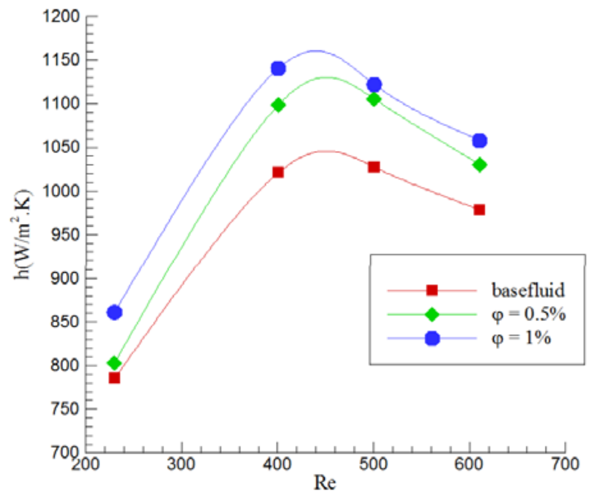

Fig.12. Convective heat transfer coefficient versus Reynolds number

Table 8. Pressure drop for different fluids

Fluid	Pressure drop (mbar)
Pure water	29
Water-ethylene glycol	34.4
CuO nanofluid (φ = 0.5%)	43
CuO nanofluid (φ = 1%)	51

Figure 13 shows the pressure drop versus the volume fraction of nanofluid. At a constant flow rate, Q = 30 lit/min, the pressure drop increases by 48.2% compared to the base fluid. It can be concluded that the application of nanofluids has a desirable effect and an undesirable effect. The desirable effect is the increase in heat transfer and the undesirable effect is the increase in the pressure drop leads to more pumping power.

5. Conclusions

In the present paper, the effect of water-CuO nanofluid on the radiator heat transfer of an automobile, Peugeot 405 XU7 engine type was investigated experimentally. The results showed that the heat transfer coefficient increases with the volume fraction. Convective heat transfer coefficient had a maximum at

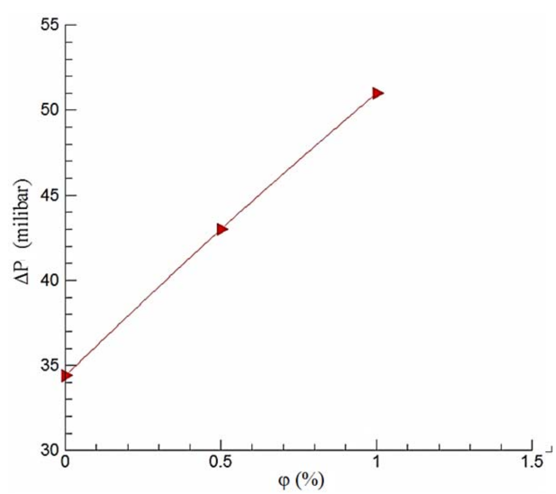

Fig. 13. Radiator pressure drop versus volume fraction of nanofluid

volumetric flow rate Q = 20 lit/min. The Nusselt number reaches its maximum at the Reynolds 400 for a constant volume fraction. At low Reynolds numbers, the amount of heat transfer of the nanofluid does not significantly increase compared to the base fluid. The results demonstrated that heat transfer at a high speed of fan is 33.7% larger than that at low speed for volume fraction of 1%. It was revealed that the pressure drop versus the volume fraction of nanofluid.

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