AN EXPERIMENTAL STUDY ON COOLING PERFORMANCE OF A CAR RADIATOR USING Al_2O_3-ETHYLENE GLYCOL/WATER NANOFLUID

by

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Nanofluids have high thermal conductivity and can be used as vehicle engine coolant. In this article, the effects of Al_2O_3 nanoparticles to an engine coolant were experimentally investigated and the results were compared with the results of the original coolant including 50% ethylene glycol and 50% water mixture. The nanofluid was prepared by adding 0.5% Al_2O_3 nanoparticles by volume. The inlet temperature of the coolant was held constant at 95 °C. The tests were carried out at the air inlet temperatures between 23.4-28.6 °C, the air velocity between 1.7-4.3 m/s, the cooling power between 2.5-15 kW and the cooling fluid flow rates between 10-25 Lpm. The results show that nanoparticles increase the cooling performance of the engine radiator. By using Al_2O_3 nanoparticles, cooling power of the radiator has increased up to 17.46% compared to original case.

Key words*: nanofluids, automobile radiators, cooling power, engine coolant*

Introduction

Nanofluid was firstly introduced by Choi and Eastman [1]. His research results were indicated that nanofluid usage has increased the heat transfer compared to the conventional fluids. Most of the results show that the thermal conductivity of the nanofluid is higher than the base fluids [2, 3]. Nanofluid is a fluid, which contains nanometer-sized solid particles. Nanofluids can be produced by dispersing a typical size of less than 100 nm of metallic or non-metallic nanoparticles or nanofibers in a base liquid. Two different methods are used for nanofluid production. These methods are single-step method and two-step method [4].

Nowadays, internal combustion engines produce high powers. Thus, an increase in the thermal stresses and thermal loads are inevitable. In the internal combustion engines, 10-25% of the combustion heat is lost to the engine cooling system at the full load conditions. This heat loss increases at the part loads and reaches a value higher than 30% at zero load [5]. In recent years, high cooling efficiency of a vehicle radiator has become imperative with the

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rapid development of the vehicle engine performance. However, traditional approach of the enhancing cooling rate such as using the compact micro channels or fins has already reached to the their limits. In addition, the conventional heat transfers of fluids, such as the water and the EG, have the low thermal conductivity, which leads to the low heat transfer performance. Therefore, it is highly desired to find innovative and effective heat transfer fluids to improve the vehicle radiator cooling rate [6]. In order to enhance the heat transfer performance of the engine cooling systems, some researches focused on the nanofluids usage for the vehicle radiators. Tzeng *et al.* [7] experimentally investigated the performance of the CuO-water and the Al_2O_3-water nanofluids in the vehicle cooling system. Their results showed that the CuO-water nanofluid has the lowest temperature distribution in both the high and low speeds. Peyghambarzadeh *et al.* [8] compared the heat transfer performance of the pure water, the pure ethylene glycol (EG), the Al_2O_3-water and the Al_2O_3-EG nanofluids. Their experimental results indicated that the highest Nusselt number enhancement up to 40% for both nanofluids. Chougule and Sahu [9] experimentally investigated the convective heat transfer enhancement of the CNT which is the nanofluid inside for an automobile radiator. The results showed that both nanocoolants introduce huge amount of change in the Nusselt numbers compared with the water and the CNT nanocoolant with 5.5 pH showed the best performance. Hussein *et al.* [10] enhancement heat transfer for car radiator using TiO_2 and SiO_2 nanoparticles. They used water as a base fluid and results showed that the heat transfer increases with increasing of nanofluid. Goudarzi and Jamali [11] studied on a car radiator with coil inserts experimentally. They found that thermal performance enhancement up to 5% as compared to the use of coil inserts alone. Moghaieb *et al.* [12] studied engine cooling system performance using Al_2O_3-water nanofluids. The results showed that the heat transfer is directly proportional with the flow velocity and inversely proportional with the bulk temperature. Asadi *et al.* [13] studied an experimental and theoretical investigation about cooling fluid in thermal and energy management applications. Other than the experimental studies on the actual vehicle engine previously discussed, many researchers have the set-up experimental test rigs and performed their experiments which are similar to the condition of the actual engine vehicles. Ettefaghi *et al.* [14] studied oil-based nanofluid. Elias *et al.* [15] studied Al_2O_3 nanoparticles in car radiator coolant and they found that thermal conductivity, viscosity, and density of the nanofluid increased with the increase of volume concentrations. Chougule and Sahu [16] compared with Al_2O_3-water and CNT-water. The heat transfer performance of CNT-water nanofluid was found to be better than Al_2O_3-water nanocoolant. Leong *et al.* [17] investigated performance of nanofluid-based coolants in a radiator. It is observed that, about 3.8% heat transfer enhancement could be achieved with the addition of 2% copper particles in the base fluid at the Reynolds number of 6000 and 5000 for air and coolant respectively. Nieh *et al.* [18] studied relationship of the heat dissipation capacity and pumping power by using the efficiency factor. The experimental results showed that heat dissipation capacity and efficiency factor of the nanocoolant higher than EG-water. Mert [19] studied on nanoparticle usage in a real size car radiator and conditions close to the reality. On the other hand, there are also some numerical studies on nanofluids used in the vehicle radiators for future studies. Hatami *el al.* [20] studied different shapes of nanoparticles. Delavari and Hashemabadi [21] studied CFD simulations of heat transfer in a car radiator. Vajjha *et al.* [22] developed new correlations for the Nusselt number and the friction factor under flat tubes. Bhattacharyya *et al.* [23] studied heat transfer enhancement of laminar flow of EG through a square channel fitted with angular cut wavy strip. Their results showed that use of angular cut wavy tape leads to considerable increase in heat transfer when compared with no angular cut wavy tape. This result is useful for the design of heat exchangers. Tahat and Benim [24] studied thermophysical properties of Al_2O_3/CuO/water/EG hybrid nanofluids and its effect on thermal efficiency. In their study the efficiency of a collector was improved by 45% by increasing the nanoparticle weight fraction.

From the literature review, it can be seen that many of these investigations have not focused on the real engine cooling conditions. This study aims to investigate a real size car radiator and conditions close to the reality. Therefore, Al_2O_3 nanoparticles have been added to the engine coolant (including 50% EG and 50% water) and a radiator set-up was designed for this purpose. The nanofluid that consists of EG-water-nanoparticles mixture including 0.5% of Al_2O_3 was prepared and tested at the air velocity between 1.7-4.3 m/s, the cooling loads between 2.5-15 kW and the cooling fluid flow rates between 10-25 Lpm.

Experimental methodology

Preparation and properties of the nanofluid

Nanoparticles such as Al_2O_3, CuO, TiO_2, SiC, MWCNT are commonly used in the studies of nanofluid usage in the automobile radiators, mini or micro-channels [25, 18]. In this study, the Al_2O_3 nanoparticle was used in preparation of the nanofluid. The Al_2O_3 nanoparticle's properties are given in tab. 1.

Table 1 Properties of nanoparticles and base fluid used in the experiments [26, 27]

Nanoparticle /base fluid	Purity [%]	Average grain size [nm]	Specific surface area [m^2g^{-1}]	Shape	ρ [kgm^{-3}]	C_p [$Jkg^{-1}K^{-1}$]	k [$Wm^{-1}K^{-1}$]
Al_2O_3	99.8	13	85-115	Close to spherical	3890	778	46
Water/EG	50:50				1110	3354	0.3712

The nanofluids are prepared using two step synthesis methods. The nanofluid was prepared for 0.5% volumetric concentration. The nanoparticles were dispersed in a base fluid during 30 minutes with the help of a probe type ultrasonic homogenizer (Brand/Type: Optic Ivymen System/CY–500, Power: 500 W, Frequency: 20 kHz, Probe Diameter/Length: Ø5.6/60 mm). The Al_2O_3 nanoparticles and 50% EG-water base fluid were weighed with a precision balance. (Brand/Type: AND GX–600, Max Mass: 610 g, Deviation: 0.001 g). After Al_2O_3 nanoparticles were added to 50% EG-water base fluid in a 600 mL glass beaker, they were placed in a 25 °C heat bath whose temperature was being checked. (Brand/Type: Cole Parmer/EW–12108–25, Temperature: –20~200 °C, Bath Capacity: 6 L, Heating Power: 1 kW, Cooling Power: 200 W, Flow Rate: 11~24 Lpm). The mixture was subjected to ultrasonic vibration by a probe type homogenizer. Any surface-active agent was not used. Figure 1 shows the nanofluid preparation process and the used devices.

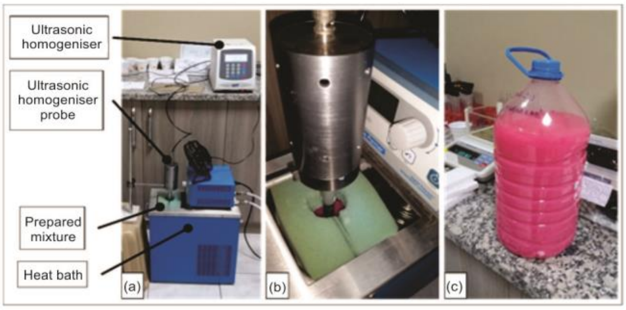

Figure 1. The nanofluid preparation process and the used devices; (a) preparation equipment, (b) probe and mixing zone, and (c) prepared nanofluid

This study was carried out within a project supported by the Scientific and Technological Research Council of Turkey (TUBITAK). In the project, optimization and stability analyses related to the nanoparticle concentration were also performed, and the results were presented in a published article [28]. In this article, the stability analyses results showed that the most suitable Al_2O_3 concentration was 0.5% in order that nanoparticles do not sedimentation in the radiator. For this reason, radiator experiments were carried out taking these results obtained in the project into consideration. The radiator tests were made with two different coolants; 50% EG-water mixture and a nanofluid of 50% EG-water base fluid including Al_2O_3 nanoparticles with a volumetric concentration of 0.5%.

Density of the nanofluid was defined using [29]:

$$\rho_{\mathrm{nf}} = \rho_{\mathrm{np}}\phi + \rho_{\mathrm{bf}}(1-\phi) \tag{1}$$

where, ρ [kgm^{-3}] is density, ϕ [%] – the volumetric concentration. The subscripts nf, np, and bf refer to nanofluid, nanoparticle, and base fluid respectively.

Specific heat of the nanofluid was calculated by [30]:

$$c_{\mathrm{nf}} = \frac{\rho_{\mathrm{np}} c_{\mathrm{np}}\phi + \rho_{\mathrm{bf}} c_{\mathrm{bf}}(1-\phi)}{(1-\phi)\rho_{\mathrm{nf}} + \rho_{\mathrm{np}}\phi} \tag{2}$$

Cooling power of the radiator was calculated using:

$$\dot{Q} = \dot{m}c(T_{\mathrm{in}} - T_{\mathrm{out}}) \tag{3}$$

where, $\dot{m}$ is mass-flow rate, c [Jkg^{-1}K^{-1}] – the specific heat of the coolant, T_{in} and T_{out} are the inlet and outlet temperatures of the coolant, respectively.

The test rig and the procedure

An experimental set-up which requires in small quantities of nanofluids has been established in Sakarya University's laboratory. A detailed schematic figure and the picture of the set-up are shown in figs. 2 and 3, respectively.

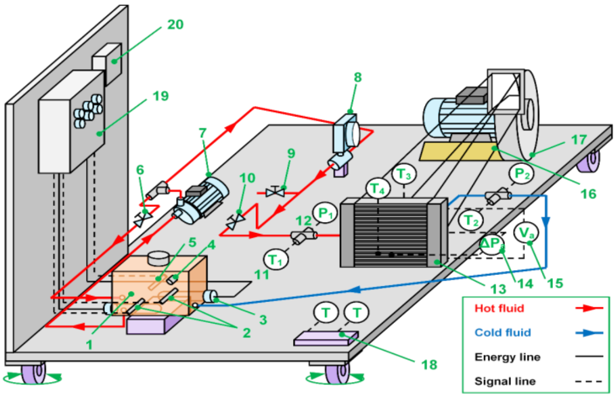

Figure 2. Schematic demonstration of the experimental set-up; *1 – fluid reservoir, 2 – liquid level electrode, 3 – Resistance, 4 – expansion valve, 5 – thermostat sensor, 6 – by-pass valve, 7 – pump, 8 – flowmeter, 9 – discharge valve, 10 – main valve, 11 – temperature sensor, 12 – pressure sensor, 13 – radiator, 14 – differential manometer, 15 – differential manometer, 16 – air duct, 17 – fan, 18 – data acquisition device, 19 – resistance con-trol, and 20 – frequency converter* (*for colour image see journal web site*)

A special fabrication radiator was used for the experiments. Specifications of the test radiator is given in tab. 2.

Circulating pumps are used to spread the coolant over the cooling system of the vehicles. The coolant pipes and the transition areas have the dimensions large enough. The pump load does not have a significant impact on the pump. In the experimental set-up, diameters of the coolant pipes were chosen smaller than real case in order to use less amount of nanofluid.

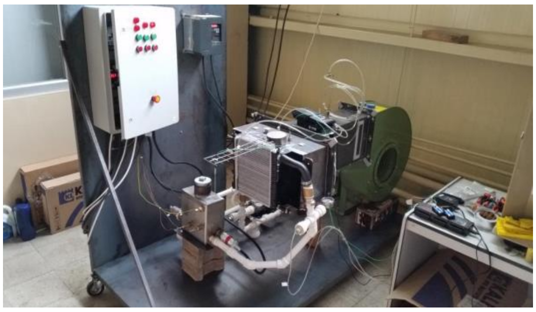

Figure 3. The picture of the experimental set-up

Under normal circumstances, the axial fan is placed with the vehicle's radiators and the fan activates in order to cool the fluid in the radiator when the vehicle stops or moves with a low velocity. At the higher velocities of the vehicle, air enters the radiator with a high velocity and the sufficient cooling is provided so the fan is not needed. In the experimental set-up, all the system is stationary and therefore an adjustable air source which can be adjusted to discharge the air into the radiator fast enough was used. Thus, the experiments were also performed at the high velocities (up to 50 km/h). The fast air-flow causes the high pressure losses in the radiator. A radial fan is used instead of an axial fan since axial fans can not compensate these high pressure losses.

Table 2. Structural specifications of the test radiator

Core dimensions of the honeycomb: width × height × depth	250 × 301 × 60.4 mm
Duct dimensions –outer: height × width	2 × 26 mm
Duct wall thickness	0.5 mm
Duct dimensions – inner: height × width	1 × 25 mm
Duct hydraulic diameter	1.923 mm
Number of ducts	34
Fin density	20 (fins per inch)
Fin type	Louver
Duct and Fin materials	Aluminum

Correct measurement of the inlet and outlet temperature of the coolant is one of the most important factors for the determination of the increment in the cooling capacity. The air temperature is also important to imply that the tests were performed in the same environment temperature. In order to get more accurate temperature instead of instantaneous temperature, average values are taken into account while the system is operating stable. For this reason, software interface of the device was set for 30 scans per 10 seconds for each input data (3 scan rate per second). Thus, the deviations caused by sensors and set-up which are induced instant changes were minimized. In the experiments, the radiator inlet and outlet temperature of the coolant, the coolant flow rate, the air inlet and outlet temperature, the volumetric flow rate of the coolant and the air velocity were measured.

Uncertainty analysis

According to the uncertainty analysis [31], uncertainties of the measured and the calculated values are given in tab. 3. Thermocouples were calibrated (two point calibration; boiling pure water and ice water) for every cycle of the experiments. Temperature measuring error is verified as ± 0.1 $^{\circ}$C.

Result and discussion

The experimental results of the cooling power are presented below at the operating conditions (nanoparticles volume concentration of 0.5%, the air velocity from 1.7 to 4.3 m/s and the volumetric coolant flow rate 10 to 25 Lpm).

The cooling power *vs*. the air velocity, at the different coolant volumetric flow rates are shown in the figs. 4-7. In these figures, EGW indicates the base coolant, which consists of 50% EG and 50% water, and EGW+nanoparticle indicates the Al_2O_3 included nanofluid, which consists of 0.5% Al_2O_3 nanoparticles by volume. It can be seen from the figures that cooling power of the nanofluid increased compared to EGW coolant for all the air velocities.

Table 3. The uncertainty of measured or calculated values

Parameter	Uncertainty [%]
Temperature difference	∓2.69
Mass-flow rate	∓2.51
Cooling power	∓4.07
Air velocity	∓3.91
Coolant velocity	∓0.74
Volumetric flow rate	∓2.50

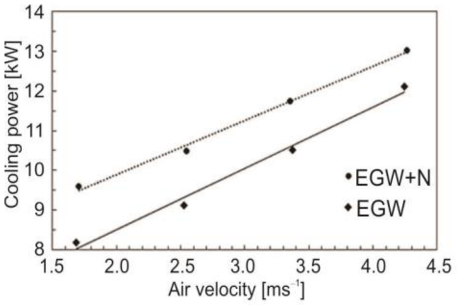

Figure 4. Cooling power curves for volumetric flow rate of 10 Lpm

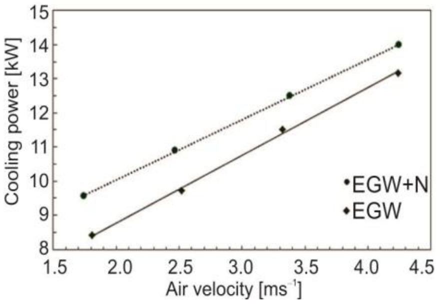

Figure 5. Cooling power curves for volumetric flow rate of 15 Lpm

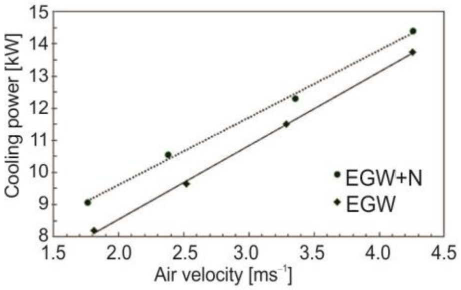

Figure 6. Cooling power curves for volumetric flow rate of 20 Lpm

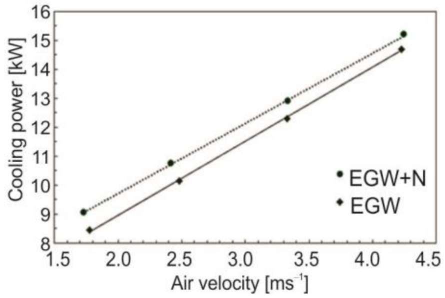

Figure 7. Cooling power curves for volumetric flow rate of 25 Lpm

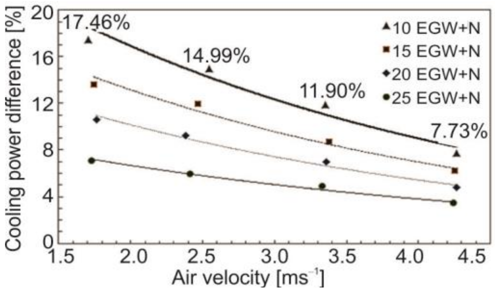

Figure 8. Cooling power difference of the nanoparticle added coolant for different volumetric flow rates

Figure 8 shows the differences between the cooling power of the nanofluid and the base coolant. It can be seen from the figure that the difference decreases with increasing coolant volumetric flow rate. The maximum difference was obtained at the volumetric flow rate of 10 Lpm and the air velocity of 1.7 m/s as 17.46%.

Nambeesan *et al*. [32] obtained a 37% improvement in the heat transfer performance of the automobile radiator with the addition of 0.1% Al_2O_3 nanoparticles to the engine coolant. On the other hand, the experimental results of Subhedar *et al*. [33] indicated that the Nusselt number increased between 3.89-28.47% by adding 0.2-2.8% Al_2O_3 nanoparticles to the coolant of an automobile radiator. The results obtained in this manuscript seem to be more compatible with the results obtained by Subhedar *et al.* [33]. It is concluded that 37% increase in the heat performance obtained by Nambeesan *et al.* [32] with a very low nanoparticle concentration (0.1%) seems to be a very high.

Conclusions

In this study, the cooling power of the engine coolant including Al_2O_3 nanoparticles was experimentally investigated for the low vehicle speeds and the results were compared with the experimental results of the base coolant, which contains 50% EG and 50% water. The conclusions can be summarized are as follows.

- The cooling power of the nanofluid increased compared to the EGW coolant for all air velocities.
- The cooling power increased with increasing the air velocity.
- The cooling power increased with all the volumetric coolant flow rates.
- The percentage increase in the cooling power of the nanocoolant was decreased with increasing flow rate.
- By using the nanofluid, the maximum percentage increase in the cooling power of the coolant was obtained as 17.46% at the volumetric flow rate of 10 Lpm.
- These results are in line with the results of previous research which indicated that the nanofluids can be used as the engine coolant and minimize the dimensions of radiators of vehicles.

Nomenclature

c – specific heat, [$\mathrm{Jkg^{-1}K^{-1}}$]
$\dot{m}$ – mass-flow rate, [$\mathrm{kgs^{-1}}$]
$\dot{Q}$ – cooling power, [kW]
T – temperature, [K]

Greek symbols

ρ – density, [$\mathrm{kgm^{-3}}$]
ϕ – volumetric concentration, [%]

Subscripts

bf – base-fluid
nf – nano-fluid
np – nano-particle
EGW – ethylene-glycol-water
EGW+N – ethylene-glycol-water+nanoparticle

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