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NANOFLUID AS A COOLANT IN AUTOMOTIVE RADIATORS

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ABSTRACT

The present paper reports an experimental work on thermal performance of silver/water nanofluids in a radiator. Silver nanoparticles were dispersed in distilled water using the two-step method, high-pressure homogeneizer, with concentration varying from 0.1% and 0.3% in volume. The thermal conductivity and the viscosity were measured showing an enhancement up to 18% and 5%, respectively, in relation to the base fluid. An experimental facility was built for this purpose and tests have been conducted under the following conditions: inlet air temperature of 25^{o}C, inlet hot fluid temperature of 45^{o}C. The experimental results show similar results in the temperature difference of hot fluid for concentration of 0.3%, and nanofluid presented high heat transfer for the high velocities of the cooling air.

INTRODUCTION

Nanofluids are a new class of fluids engineered by dispersing nanometer-size solid particles in base fluids such as water, ethylene glycol or oil, for example. Regarding to the thermal potential, the researches on nanofluids increased significantly in the last years. Thermal conductivity is the property that has catalyzed the attention of the nanofluids research community the most. As dispersions of solid particles in a continuous liquid matrix, nanofluids are expected to have a thermal conductivity that obeys the effective medium theory developed by Maxwell in 1873. Normally, as expected, these fluids are homogeneous and stable solutions for a short period of time, which in some applications, equipment and process are not desired. To extend the stability of nanofluids is common the use of surfactants, which are substances that cause electrostatic repulsion between nanoparticles and the base fluid molecules. However, this process changes the thermal properties of the pure nanofluid, in general, reducing the thermal conductivity and consequently, the heat transfer potential.

This new class of thermal fluid seems to be potential replacement of conventional coolants in refrigeration and air conditioning systems, engine cooling system and other applications. Many experimental studies focused on the measurement of transport properties of nanofluids. In relation to the convective heat transfer, Wen and Ding (2004) investigated nanofluids under laminar flow. Pak and Cho (1998), Xuan and Li (2003) performed a study on convective heat transfer under turbulent flow in tubes and the results were conflicting. Leong et al. (2010) investigated the thermal performance of copper nanofluid inside an automotive radiator and they found that the air frontal area could be reduced in 18.7% with Reynolds varying from 5000 to 6000. Many authors have been proposed correlations to calculate the heat transfer and pressure drop of fluids inside tubes, for example Saiz Jabardo et al. (1999) and Wang et al. (1999).

Nanofluids can be produced, basically, by two methods such as one step and two steps. (1) the one-step direct evaporation method represents the direct formation of the nanoparticles inside the base fluids, and (2) the two-step method represents the formation of nanoparticles and subsequent dispersion of the nanoparticles in the base fluids. In either case, the preparation of uniformly dispersed nanofluid is essential for obtaining stable reproduction of physical properties or superior characteristics of the nanofluids. It is important to mention that the one-step method is expensive, however it is possible to get higher stability and the two-step method is cheaper and difficult to get the stability for long time. In this case is common the use of ultrasonic bath to disperse the powder in the base fluid. Many researches have used surfactants to guarantee the stability, however the nanofluid properties are strongly modified.

In the automotive industry, nanofluids have enormous applications potential. Engine oils have poor thermal properties and can benefit from high thermal conductivity of nanofluids. The use of a fluid with better thermal properties in the cooling system can improve the heat transfer, allowing smaller size and better positioning of the radiators, and less energy is spent to overcome aerodynamic drag. Furthermore, the engine could operate at higher temperatures, allowing more power without extrapolate gases emissions limits. The main goal of this work is to compare the efficiency of an automotive radiator using a conventional coolant and nanofluids.

NOMENCLATURE

Q	[-]	Power dissipated
μ	[cP]	Viscosity
k	[W/mK]	Thermal conductivity
q	[W/m]	Heat flux by length
T	[ºC]	Temperature
t	[s]	Time

Subscripts

eff	Effective (relative to the base fluid)

EXPERIMENTAL SET-UP

The air circuit was built to adjust and measure the air conditions upstream and downstream of the testing coil. According to the Fig. 1 it is possible to observe that this is accomplished by electrically heating the air after mixing it with ambient air from the admission duct in the plenum. After being heated, the air flow is straightened in a honeycomb rectifier before entering the coil. After leaving the coil, the air is directed toward a volumetric flow rate measuring section, which includes a nozzles plate and two flow rectifiers located upstream and downstream of the plate. The nozzles plate includes five aluminum nozzles of different diameter in order to allow readings of a wide range of volumetric flow rates. Upon leaving the flow measuring section the air is directed toward the entrance of the circulating fan. The fan is run by a motor acted upon by a frequency inverter in such a way that the air flow rate through the coil can be varied over a wide range. The fan discharge duct presents a bifurcation and one of the ducts discharges air into the external ambient and the other directs the air for recirculation in order to reduce the heating power. The returned air is mixed with the external one in the mixing plenum. The heating fluid circuit includes a constant temperature heat exchanger, that mantains the fluid temperatur constant, a gear pump, a Coriolis mass flow meter and the testing coil. The water flow rate is adjusted by a frequency inverter connected to the pump. The temperature control of the storage tank water is performed by a PID controller. The measured parameters are the following: the coil average inlet and exit temperatures of the air and the water, the mass flow rate of the water, the volumetric flow rate of the air, and the pressure drop of the air across the coil and the nozzles plate. The temperature of the air in the cross section of the incoming and exit ducts of the coil are obtained by connecting in parallel a mesh of thermocouples covering the section in such a way to directly determine the average value of the temperature. Type T thermocouples are used in all the temperature measurements. As mentioned before, the mass flow rate of the water was obtained by a Coriolis flow meter. A calibrated set of five nozzles, installed in a plate according to ASHRAE Standard 41.2, allows for an accurate measurement of the volumetric flow rate of the air. The volumetric flow rate of the air is measured in terms of the pressure drop across the nozzles plate measured by a differential pressure drop transducer. A similar differential pressure transducer is used in the measurement of the pressure drop of the air in the testing coil. The measuring uncertainty of these parameters can be found in Table 1. Each thermocouple used in the bench has been calibrated along with the data acquisition system in a thermostatic bath, with the uncertainty being determined as recommended by Abernethy and Thomson (1973). The differential pressure transducers accuracy was obtained from a certificate provided by the manufacturer. Confirmation tests with a water U tube have been performed in order to check for the manufacturer suggested accuracy.

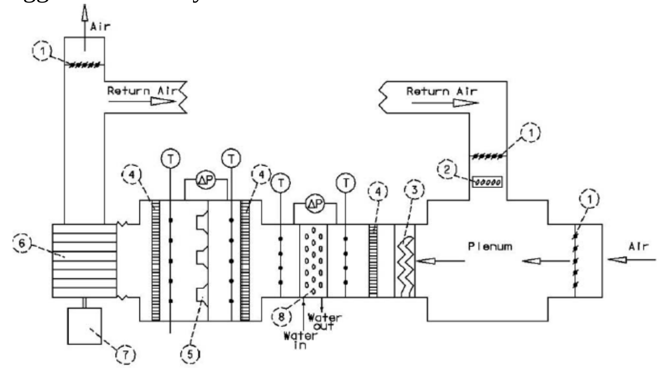

Figure 1: Schematic diagram of the air loop. 1- Damper; 2- cooling water; 3- heating coils; 4- flow straightener; 5- air flow measurement chamber; 6- circulating fan; 7- driving motor and frequency converter; 8- coil under test.

Parameter	Uncertainty
Temperature	0.14 ºC
Pressure drop in coil	0.96 Pa
Pressure drop in nozzle plate	0.74 Pa
Mass flow rate of water	0.15%
Mass flow rate of air	2.10%

Table 1: Uncertainty of measured parameters.

2.1 Preparation Method

The preparation of the nanofluid was performed using the two-step method. Silver nanoparticles of 10 and 80 nm were bought from Nanostructured & Amorphous Materials, which the main characteristics are shown in Table 2.

Silver nanoparticle		
Diameter	10nm	80nm
Form	powder	powder
Density (kg/m³)	10491	10491
Melting point (ºC)	960.8	960.8
Boiling point (ºC)	2210	2210
Solubility in water	Insoluble	Insoluble
Flamability	Highly flammable	
Dangerous reactions	Acetylene or Ammonia	
Purity	99%	99.9%
shape	spherical	spherical
Specific area (m²/g)	9 - 11	9 - 11

Table 2. Data and properties of silver nanoparticle.

In this work, the dispersion of the nanoparticle in the base fluid, in this case distilled water, was made using the high-pressure homogenizer. The high pressure homogenizer was the most effective methods among the two steps methods, it consists of two microchannels that divide the feed stream into two others streams. The both liquid streams divided were then recombined in a reacting chamber. Here the significant increase in the velocity of pressurized liquid streams in the micro-channels resulted in the formation of cavitations in the liquid. The high energy of cavitations was used to break the clusters of nanoparticles. In the fast flow region, particle clusters must be broken by the combination of various mechanisms, including (1) strong and irregular impaction on the wall inside the interaction chamber, (2) microbubbles formed by cavitation-induced exploding energy, and (3) high shear rate. This leads us to finally obtain very homogeneous suspensions with less aggregated particles, Hwang et al. (2007).

2.2 Thermal Conductivity Measurement

The measurement of thermal conductivity of nanofluids was performed using the hot wire method. The advantages of this method are its almost complete elimination of the effects of natural convection and the fast measurement compared with other techniques. The transient hot wire method measures the temperature response of the wire with time for an electrical power. The system consists of the electrically insulated platinum wire in the fluid and the cylindrical bath. The hot wire sensor system with 75 μm diameter is located at the center of the cylinder and the alignment to the direction of gravity is adjusted.

The thermal conductivity is calculated by Fourier Law, based on ASTM D5334-08, as follow:

$$k = \frac{q}{4\pi \Delta T} \ln(t_2 - t_1)$$

where, q is the heat flux by lenght, T and t are the wire temperature and time, respectively, and k is thermal conductivity of the fluid.

2.3 Viscosity Measurement

There are a few methods to calculate the effective viscosity of fluids. A simple method is to use high shear viscosity. In this apparatus the shear stress is measured in small fluid samples, beyond of calculate the necessary force to run the conic element, spindle. The volume of liquid necessary for the tests was approximately 500 ml and to guarantee constant temperature a thermal bath was also used to maintain the temperature of 298 K. The rheometer used in the present investigation was calibrated with distilled water, presenting a measured viscosity of 0.89 cP.

RESULTS

Thermal conductivity is one of the main properties to be analyzed in nanofluids. It is important to note that the volumetric concentration and the nanoparticle size have direct influence in this property and the present work concentrates in analyze the influence of these parameters in the experimental results. Fig. 2 presents the increase of thermal conductivity in function of the volumetric concentration of silver nanoparticles dispersed in distilled water for different nanoparticle sizes and its respectively uncertainties bars. The results show that the thermal conductivity increased with the volumetric concentration, as expected, and specifically for 0.3% the enhancement obtained for the thermal conductivity was 18%. It is important to note that the real concentration obtained for the tested nanofluids was lower than the nominal in the initial preparation process. This fact mainly is related to the nanoparticles losses in the preparation process in the high-pressure homogenizer. As can be noted in the Fig. 2, it is not possible to conclude about the nanoparticle size influence in the thermal conductivity, since for concentrations 0.1 % and 0.2 % the experimental results were higher for 80 nm, meanwhile for 0.3% the nanoparticles with 10 nm the results obtained for thermal conductivity were higher.

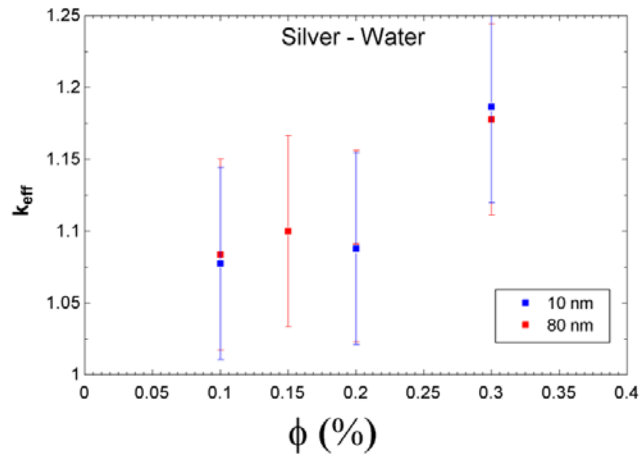

Figure 2: Experimental results for thermal conductivity of silver nanofluids tested in the present work.

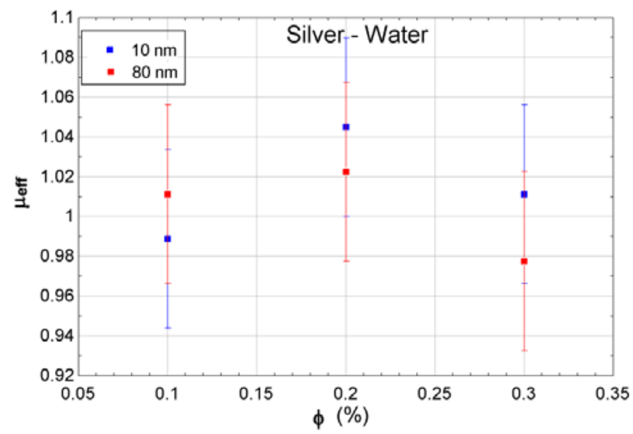

Figure 3: Experimental results for relative viscosity of silver nanofluids tested in the present work.

The thermal performance of the radiator was evaluated using the temperatures of the hot fluid (silver nanofluid and distilled water). As can be observed in the Figs. 4 to 7, that shows the differential temperature by the air velocity, for each liquid flow, the temperature difference between the inlet and outlet hot fluid increases with the air velocity, as expected. The tests were performed in five different air face velocities and the results of DT for the silver nanofluid presented slightly lower values compared to the water, and this DT for nanofluid overcame the DT for the water in the higher air velocity.

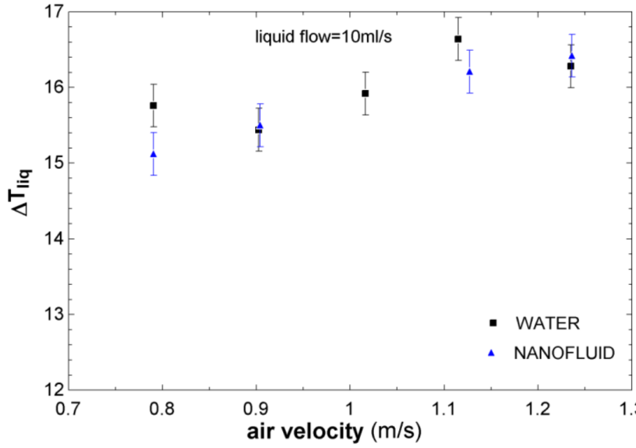

Figure 4: Experimental results for silver nanofluid and water of thermal performance of the radiator (liquid flow = 10ml/s)

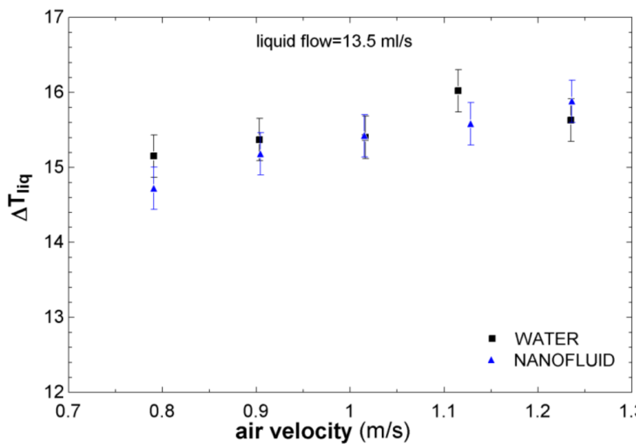

Figure 5: Experimental results for silver nanofluid and water of thermal performance of the radiator (liquid flow = 13.5ml/s)

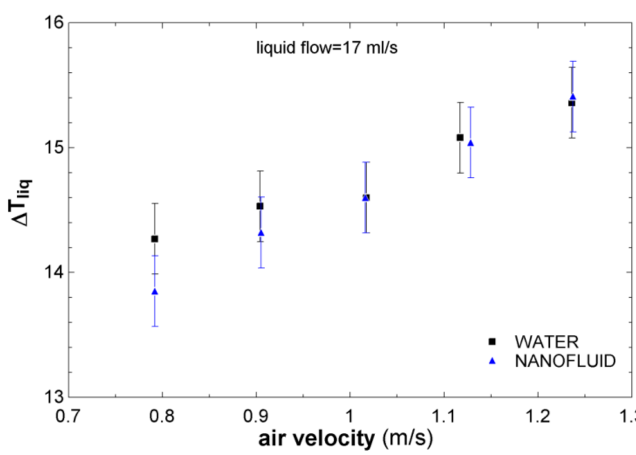

Figure 6: Experimental results for silver nanofluid and water of thermal performance of the radiator (liquid flow = 17ml/s)

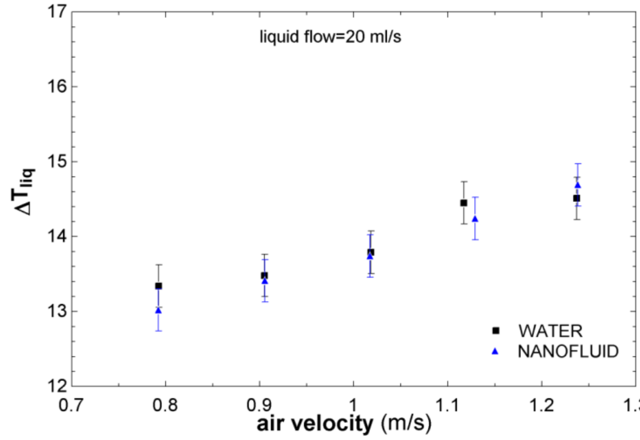

Figure 7: Experimental results for silver nanofluid and water of thermal performance of the radiator.

The Figs. 8 to 10 show the removed heat in the tests, using water and nanofluid, for each air velocity. For this calculation, as the concentration is very low, the specific heat of the nanofluid was considered the same of the water. It can be observed that for low air velocities (Fig. 8), the heat is higher for the water, and for the highet air velocity (Fig. 10), the heat is higher for the nanofluid, indicating that for the more turbulent flow, nanofluid has more capacity of increase the heat transfer.

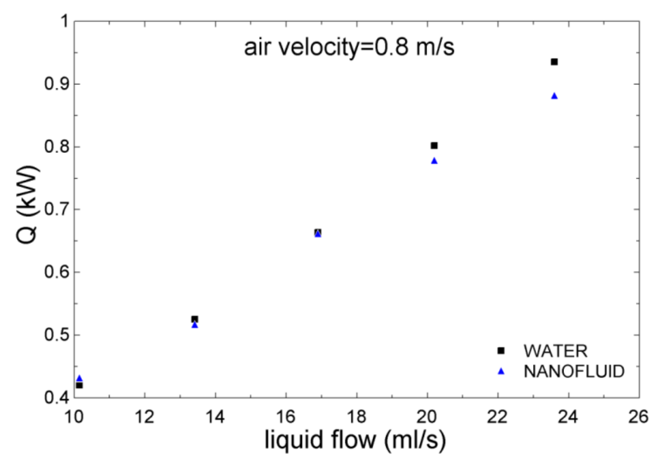

Fig. 8 – Heat transfer rate using water and nanofluid (air velocity = 0.8 m/s)

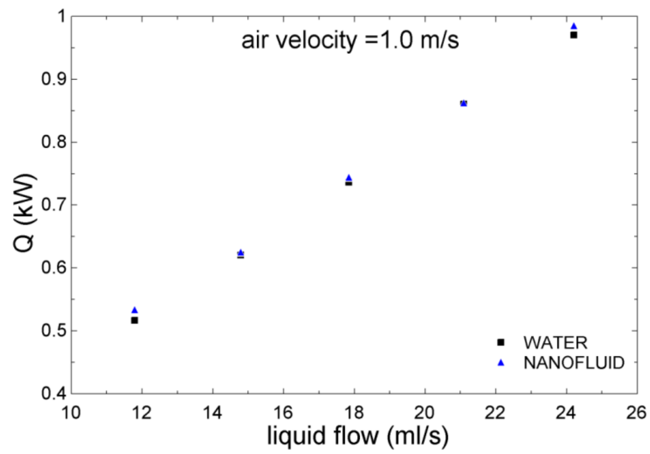

Fig. 9 – Heat transfer rate using water and nanofluid (air velocity = 1.0 m/s)

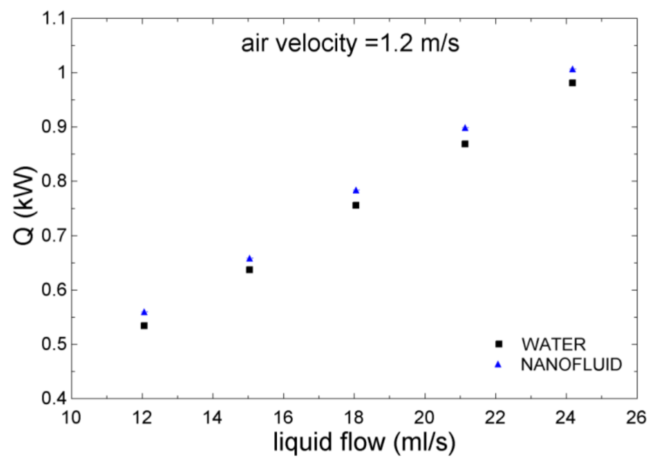

Fig. 10 – Heat transfer rate using water and nanofluid (air velocity = 1.2 m/s)

CONCLUSION

The present paper focused on the preparation, characterization and thermal performance of silver nanofluids in radiator. Silver nanofluids have been successfully prepared using a high-pressure homogenizer to disperse the nanoparticles into base fluid, maintaining the suspension stable for at least 6 months.

The thermal conductivities of silver nanofluids with 10 nm and 80 nm have been investigated. The experimental results showed, in general, that the addition of nanoparticles into distilled water led to the increase of thermal conductivity. The thermal conductivity enhancement was up to 18% for the best case with volumetric concentration of 0.3 %. In relation to the viscosity, it was found that the results obtained for silver nanofluids was, basically, the same order of the distilled water, indicating a low influence with the nanoparticle addition.

In relation to the thermal performance the experimental results indicated slightly lower values of the DT when the silver nanofluid circulated by the radiator, compared to the pure water. However, the heat transfer using nanofluid showed higher values for high air flow, indicating that for more turbulent conditions nanofluid have great potential of increasing heat transfer. However, new results are expected varying the nanofluid concentration, air velocity and temperatures.

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