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THERMAL PERFORMANCE ANALYSIS OF SILVER/WATER NANOFLUIDS IN HEAT EXCHANGERS

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Abstract. *The present work aims evaluate the thermal performance of nanofluids in heat exchangers. Silver nanoparticles were dispersed in distilled water using a two-step method, known as high-pressure homogenization, with concentration varying between 0.1% and 0.3% in volume. The thermal conductivity and the viscosity were measured using transient hot wire and cone-plate viscometer. The thermal conductivity and viscosity showed an enhancement up to 18% and 5%, respectively, in relation to the base fluid (distilled water). An experimental facility was built to evaluate the behavior of nanofluids flowing inside heat exchangers. The thermal performance of nanofluids was evaluated as a function of the liquid differential temperature between the inlet and outlet of the test coil and the results presented a discrete enhancement. New tests are needed to verify the heat transfer with nanofluids in different concentrations and inlet conditions.*

Keywords:*nanofluids, silver, water, thermal conductivity, viscosity, heat exchanger*

1. INTRODUCTION

Nanofluids are a new class of fluids formed by a dispersion of nanometer-size (1-100 nm) solid particles in common fluids (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, as can be seen in Fig. 1. 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, when compared with micro-scale, but even 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, 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. The disadvantage of one step methods is that they must be done in small and controlled amounts, and the commercial production is many times impraticable. Furthermore, the control over several parameters, such as nanoparticle size and concentration, is limited. Another restriction is that the fluid must have low vapor pressure, to avoid nanoparticle agglomeration.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. The main advantage of two step methodsis the variety of nanofluids that can be obtained, in therms of kinds of fluids and nanoparticles, and nanoparticle concentrations. The costs are substantially lower than one step methods. On the other hand, the probability of oxidation and agglomeration, in each step of the process, is high, indeed it imposes a technological barrierfor the production offluidsby these methods. In this case is common the use of surfactants to guarantee the stability, however the nanofluid properties are strongly modified.

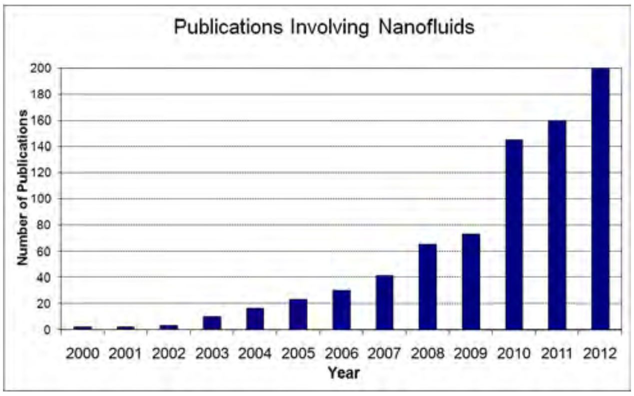

Figure 1.Number of publication according to the year in thermal sciences area.

2. EXPERIMENTAL SET-UP

The experimental bench consists of an air loop, that through the test coil, and a water circuit, that flows inside the heat exchanger. The air circuit was built to adjust and measure the air conditions upstream and downstream of the testing coil. According to the Fig. 2 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 water circuit includes a storage tank, a pump, a Coriolis mass flow meter and the testing coil. The water flow rate is adjusted by frequency inverter connected to the pump. The temperature control of the storage tank water is performed by a electrical resistance, connected to a thermostat. 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.

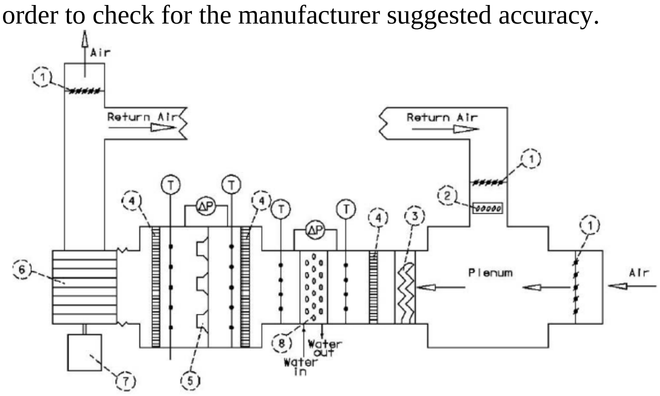

Figure 2.Schematic diagram of the air loop. 1- Damper; 2- cooling water; 3- heating coils; 4- flow straightener; 5- air flow measurement chamber; 6- circulating fan; 7- driving motor and frequency converter; 8- coil under test.

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Table 1: Uncertainty of measured parameters.

Parameter	Uncertainty
Temperature	0.14 ^{o}C
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%

2.1 Preparation method

The preparation of the nanofluid was performed using a 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. 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 an interaction 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 cavitation 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).

Table 1. Data and properties of silver nanoparticle.

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

2.2 Thermal conductivity measurement

The thermal conductivity of the fluids was measured using the transient hot wire method. The advantage of this method is the almost complete eliminationof the effects of natural convection and the fast measurement compared with other techniques. The transient hot wire method measures the temperature response of thewire with time for an electrical power. A wire Hukseflux TP-08 was used. This wire is recommended for materials with thermal conductivity between 0.1 and 6 W/m-K.

Figure 3. Wire Hukseflux TP-08 (Font: Motta, 2012).

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

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

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

2.3 Viscosity measurement

The viscosity of the nanofluids was measured using a cone-plate viscometer, model Brookfield LVDV-IIIU. This viscometer measures the shear stress of small fluid samples from a strain rate imposed in addition to determining the required torque to rotate the conical element (spindle). The geometry used in these tests was the spindle CPE 40, which requires 1ml of the fluid. In order to ensure the test temperature, the cup was connected to a thermal bath. Nanofluid was taken of different positions of the sample, to verify the repeatability of the experimental results. The rheometer used in the present investigation was calibrated with distilled water that presented measured viscosity of 0.89 cP.

3. RESULTS

The silver nanofluids produced with nanoparticles with 10 nm of diameter were evaporated and prepared to use in the Scanning Electron Microscopy, SEM. As can be noted in the Fig. 4, most of the isolated nanoparticles respect the size informed by the manufacturer and it is also possible to observe the agglomeration formed during the evaporation process, since in this method the sample cannot be prepared in the liquid phase.

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 analyzing the influence of these parameters in the experimental results. Fig. 5 presents the increase of thermal conductivity in function of the volumetric concentration of silver nanoparticles dispersed in distilled water for different nanoparticle sizes. 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. 5, 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.

The viscosity of the nanofluid samples was also evaluated. The results show, as can be seen in Fig. 6, that the increase on the viscosity was not significant, comparing to the pure water. The highest increase observed in the viscosity was 4% for a volumetric concentration of 0.2%, however as seen in Fig. 6, the observed increase was lower than the experimental uncertainty. From these results, it is not possible to infer influence of nanoparticle size on the nanofluids viscosity.

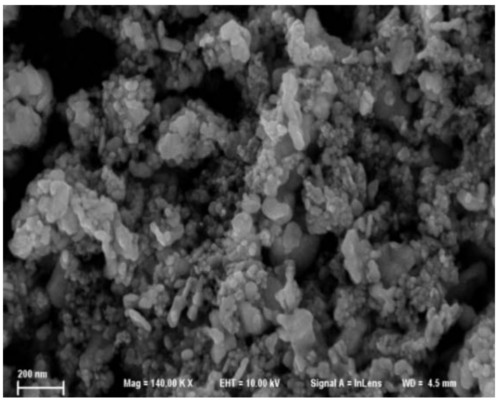

Figure 4. Micrography of silver nanoparticles in Scanning Electron Microscopy, SEM.

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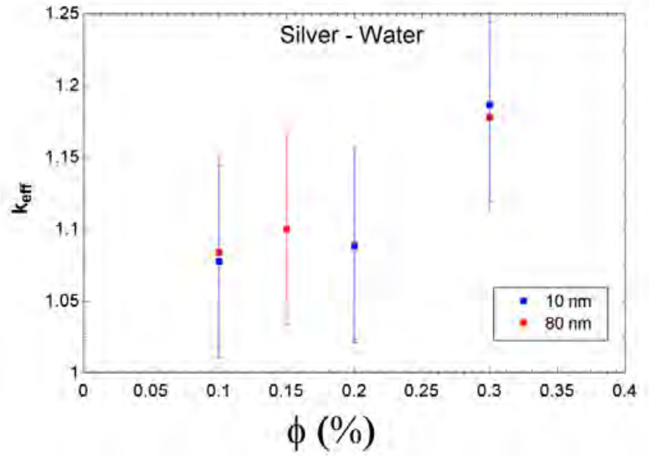

Figure 5. Experimental results for thermal conductivity of silver nanofluids tested in the present work.

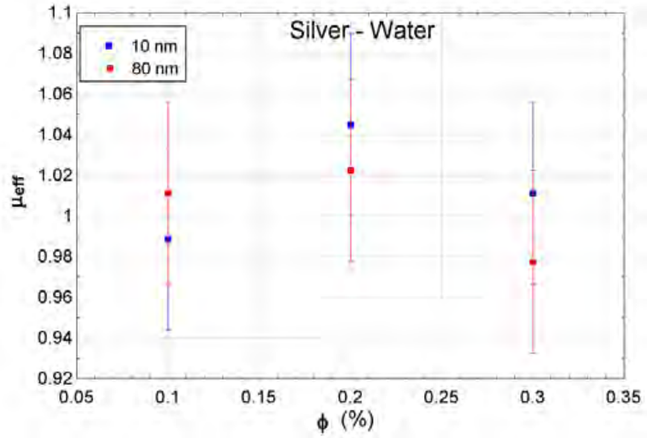

Figure 6. Experimental results for relative viscosity of silver nanofluids tested in the present work.

The thermal performance of a silver nanofluid sample (0.3%) in heat exchanger was evaluated for a given condition. For a given liquid flow rate the inlet temperatures in the air and liquid size. The performance was evaluated as a function of the liquid differential temperature between the inlet and outlet of the test coil. The Fig. 7 shows test conditions for water and nanofluid. The oscillation of the inlet temperature of the nanofluid is much higher than that of water, indicating that the nanofluid has lower thermal inertia of the water, becoming more difficult to obtain a steady state.

The tests were performed in seven different air face velocities and the results of ΔT for the silver nanofluid presented somewhat lower values in almost all range of velocities in comparison to the distilled water, indicating there is no significant increase on the heat transfer when using nanofluids, for the given conditions. These results are shown in Fig. 8.

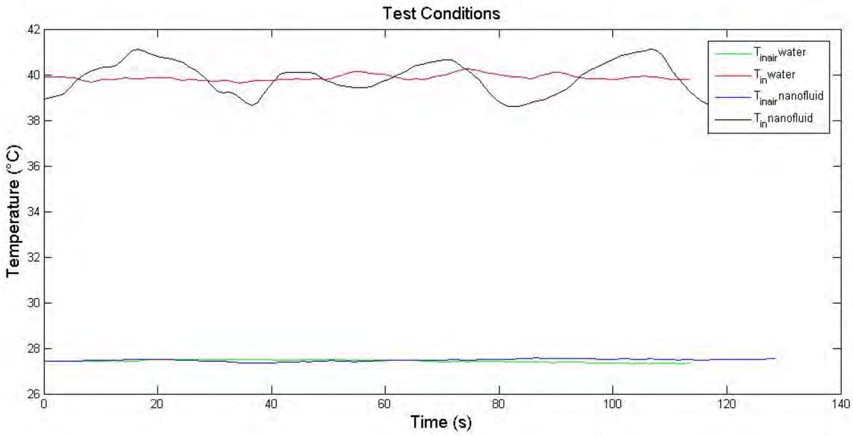

Figure 7. Inlet test conditions for base fluid and nanofluid

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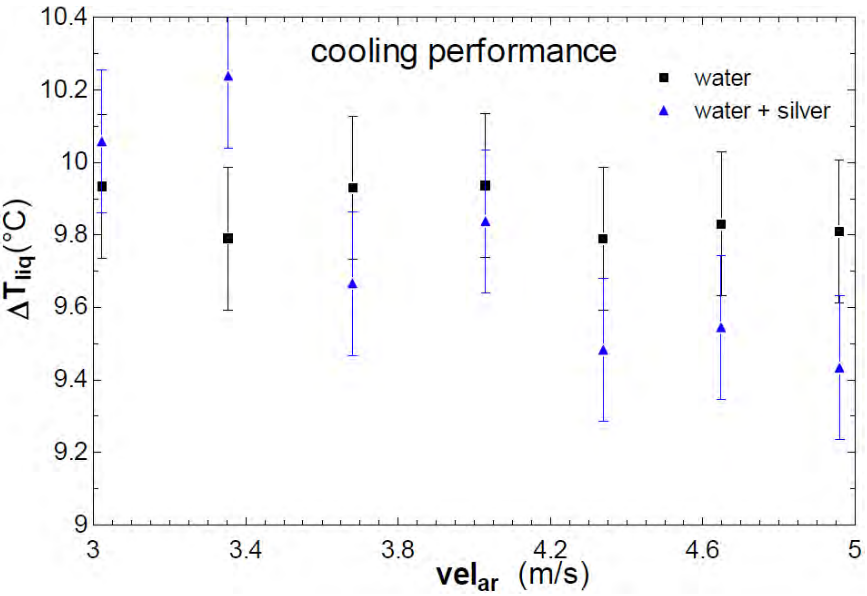

Figure 8. Temperature drop for a liquid mass flow 80g/s

It is important to mention that due to the direct contact of the electrical heater with the nanofluid, the silver nanoparticles were strongly attracted by the electrical heaters. This phenomenon caused a huge agglomeration of nanoparticles on the surface of the thermal bath, reducing the concentration of nanoparticles in the nanofluid that flows to the heat exchanger. However, new tests are needed with an indirect heater for the liquid to get new experimental results.

4. CONCLUSIONS

The present paper focused on the preparation, characterization of thermal conductivity and viscosity and thermal performance analysis of silver nanofluids in heat exchanger type fin and tube coil. Silver nanofluids in concentrations between 0.1 and 0.3% vol. have been successfully prepared using a high-pressure homogenizer to disperse the nanoparticles into base fluid, maintaining the suspension stable.

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. A significant increase on the thermal conductivity was found, up to 18% for the best case with volumetric concentration of 0.3 %. The experimental results for the viscosity of nanofluid showed a discrete increase compared to the pure water, indicating a low influence of nanoparticle addition in this concentration range.

In relation to the thermal performance the experimental results indicated somewhat lower values of the differential temperature for the nanofluid comparing to the water, when the silver nanofluid circulated by the fin and tube coil heat exchanger. It is important to note that the heating process used in these tests promoted an agglomeration of the silver nanoparticles and it should be taken into account. However, new results are expected varying the nanofluid concentration, inlet temperatures and liquid mass flow.

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7. RESPONSIBILITY NOTICE

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