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ANALYSIS OF THE REFRIGERATION CAPACITY OF SILVER NANOFLUIDS

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Abstract. *This work consists in evaluate the influence of addition of silver nanoparticles in an ethylene glycol and deionized water solution. The nanofluids were evaluated in different concentrations. Moreover, the nanofluids were subjected to an electric field in the heat transfer region to analyse the influence of the electrohydrodynamic effect. The tests have shown that the nanoparticles influence the properties of the fluids and, therefore, the amount of heat transferred. It was also presented a positive influence of the electric field, further enhancing the value of the convective heat transfer coefficient (h) in 11% when the concentration was 0,04 vol%.*

Keywords: *Nanofluids, Heat transfer coefficient, Electrohydrodynamic effect, Silver nanoparticle.*

1. INTRODUCTION

In the last decades, great advances in nanotechnology have led to the emergence of a new generation of refrigerants known as "nanofluids". These can be understood as colloidal suspensions, on the nanometric scale of solids in liquids, since the nanoparticles size is from 1 to 100 nm (Choi, 1995).

As a consequence of the inclusion of nanoparticles in fluids, nanofluids present a great thermal transfer potential, in single phase or biphasic flows. According to Laohalertdecha et al. (2007), two techniques can be applied in order to optimize thermal transfer: the active, which refers to the application of external forces (electric field or acoustic vibration), and the passives ones, related to special surfaces or an addition of elements to the fluid.

Considering nanofluids stability as one of the key points, Haddad et al. (2014) pointed out several aspects about it: nanofluids are multiphase dispersions with high surface energy and thermodynamically unstable; nanoparticles dispersed in solutions have strong Brownian motion; time influences the nanofluids stability due to the agglomeration, which is caused by Van der Waals forces; chemical reactions between nanoparticles or between base fluid and nanoparticles are not desired during working conditions.

The thermal conductivity of nanofluids containing Al2O3, CuO and Cu in two different base fluids (water and HE-200 oil) were measured by Eastman et al. (1997). With a volumetric concentration of 5 %, a 60 % increase in thermal conductivity was achieved when compared to the base fluid without addition of nanoparticles.

Patel et al. (2003) performed experiments with gold nanoparticles, using surfactant and having water as base fluid. The nanofluid was produced separately with two different diameters: 10 nm and 20 nm. It was observed an increase up to 21% in the thermal conductivity of gold nanofluids with volumetric concentration of 0.00026%. For Au/water nanofluid with 0.011 vol%, the increase in the thermal conductivity ranged from 7% to 14%. Comparatively, smaller increases in thermal conductivity were achieved for silver nanoparticles of larger diameters and with higher volume concentrations.

1.1 Eletrohydrodynamic Effect (EHD)

The electrohydrodynamic effect (EHD) refers to the application of an electric field in a dielectric fluid. In this technique, a high-voltage and low-current electric field is applied to the fluid passing between the electrodes (Laohalertdecha, et al., 2007).

According to Allen and Karayiannis (1995), the three main ways in which the electrohydrodynamic effect can improve convection heat transfer without phase change are due to (a) the corona effect, (b) electrophoresis and by action of (c) dielectrophoresis.

Robinson M. (1961) states that the corona effect refers to the movement of fluids induced by the repulsion of ions from the region near a high-voltage electrode. The ions present in the fluid will move due to the electric field forces and, after constant collisions with molecules that are not influenced by the electric field, an overall movement of the fluid will occur. In the case of electrophoresis, this is the movement of colloidal particles or polyelectrolytes immersed in a liquid and which are influenced by an electric field. Dielectrophoresis is the spontaneous movement of neutral particles subject to an intense electric field, since the difference between the permissiveness of the dielectric fluid and the medium is large (Lyklema, J., 1995).

Considering the application of the electrohydrodynamic effect in nanofluids, Asadzadeh et al. (2012) examined the influence of an electric field applied near to a heated platinum wire to evaluate the changes in thermal heat transfer by natural convection. The base fluid was ethylene glycol and the nanoparticles were Fe_3O_4 in volumetric concentrations of 0.015%, 0.02%, 0.05% and 0.1%. The authors verified that in concentrations up to 0.02% the heat transfer coefficient increased and for higher concentrations a reduction was observed. In other words, the heat transfer coefficient got lower than the heat transfer coefficient of the base fluid without nanoparticles. Also, the presence of an electric field resulted in higher heat transfers coefficients.

Savinykh et al. (1981) studied the effect that an alternating electric field would have under polar and nonpolar liquids. In order to determine the value of the thermal conductivity, a method was used in which the flow of heat passing through two flats creates, at the edges of these layers, temperature differences that are proportional to the thermal conductivities. The electric fields were 110, 150, 200 and 250 kV/m and frequency of 3.10^5, 5.10^5 and 6.10^5 Hz. The authors observed that the electric field increases the thermal conductivity value for polar and apolar fluids. Increasing the intensity of the electric field, the increments in the thermal conductivity became even more expressive. With the results, the authors suggest that the application of an electric field does not only result in electroconvection (induced convection), but also in the intensification of thermal transfer by the molecules as a result of the increase in thermal conductivity.

1.2 Objectives

The objective of this work is to evaluate the influence of different concentrations of nanofluids in the heat transfer coefficient. The nanofluids are composed of silver nanoparticles and, as base fluid, water and ethylene glycol (44/56 wt%). In addition, an electric field was applied in the thermal transfer region in order to evaluate the electrohydrodynamic effect and its consequence in the value of the thermal transfer coefficient.

2. MATERIAL AND METHODS

An experimental apparatus was developed in order to analyze the thermal transfer coefficient under forced convection conditions.

2.1 Heating Chamber

The main component of this apparatus is the heating chamber, shown in Fig. 1, where the fluid contacts a heated copper rod. As can be seen in, three thermocouples are fixed in a heated cooper rod where the nanofluid circulates. By this way, it is possible to measure the temperatures in each point (T1, T2 and T3) and then use this information to obtain the heat transfer coefficient value. It is possible to identify a laminator which helps to guarantee a laminar flow and also the presence of a heat insulation which ensures that the heat generated by the heating source is dissipated absorbed by the fluid.

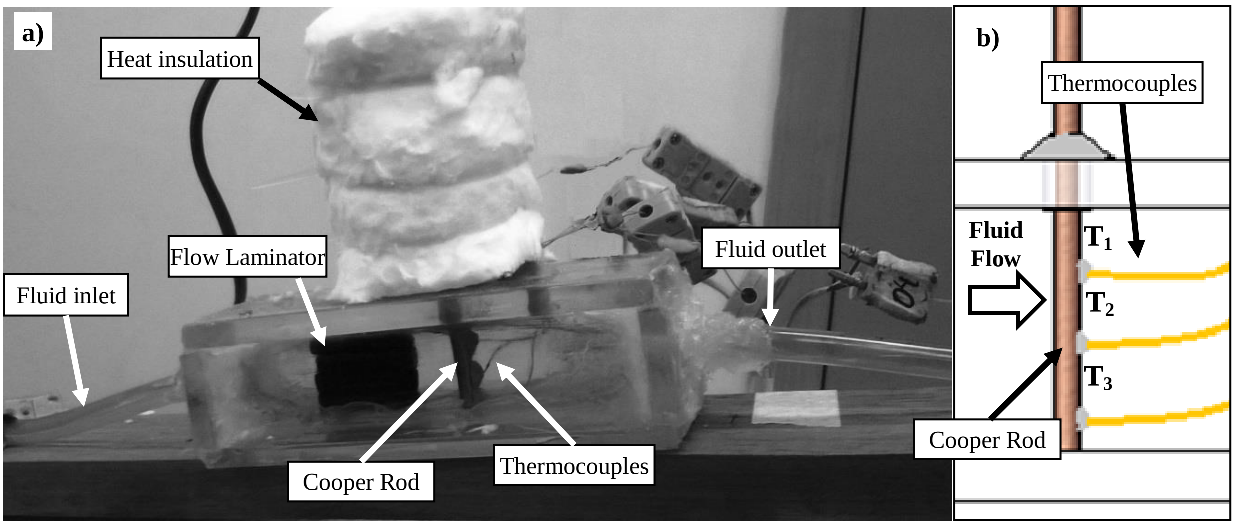

Figure 1. (a) Original heat transfer chamber; (b) Illustration of thermocouple position.

The Fig. 2 shows the positioning process of the thermocouples. Holes with diameter of 1.5 mm and deep of 2 mm were made in the cooper rod and thermal paste was added in these holes. So the thermocouples were positioned and fixed.

Figure 2. Thermocouples fixation. a) T1 fixed; b) thermal paste used in each hole.

The position of the thermocouples on the rod is a relevant information that will be used in the mathematical development to estimate the amount of heat dissipated by the rod. Thus, Tab. 1 provides the positions of each point, considering as reference the fin base. It is also presented some dimensional information of the copper rod.

Table 1. Thermocouples position and copper rod dimension.

Cooper rod dimensions		**Thermocouples position (m)**	
Length (m)	0.03	**T1**	0.008
radius (m)	0.0026	**T2**	0.017
Perimeter (m)	0.016328	**T3**	0.0255
Cross-section area (m²)	0.0000212		

2.2 Circulation System

Moreover, a circulation system was developed and its components are presented in Fig. 3. A pump (3) was used to ensure a constant fluid circulation. The pump was the component before the heating chamber (1) which was already presented. After passing through the heating chamber, the fluid was directed to a cooling unit and, after that, to the reservoir. Although it is not illustrated in Fig. 3, the electric field was applied by means of two stainless steel plates fixed near to the heated surface and connected to a High Voltage-Low Current DC power supply.

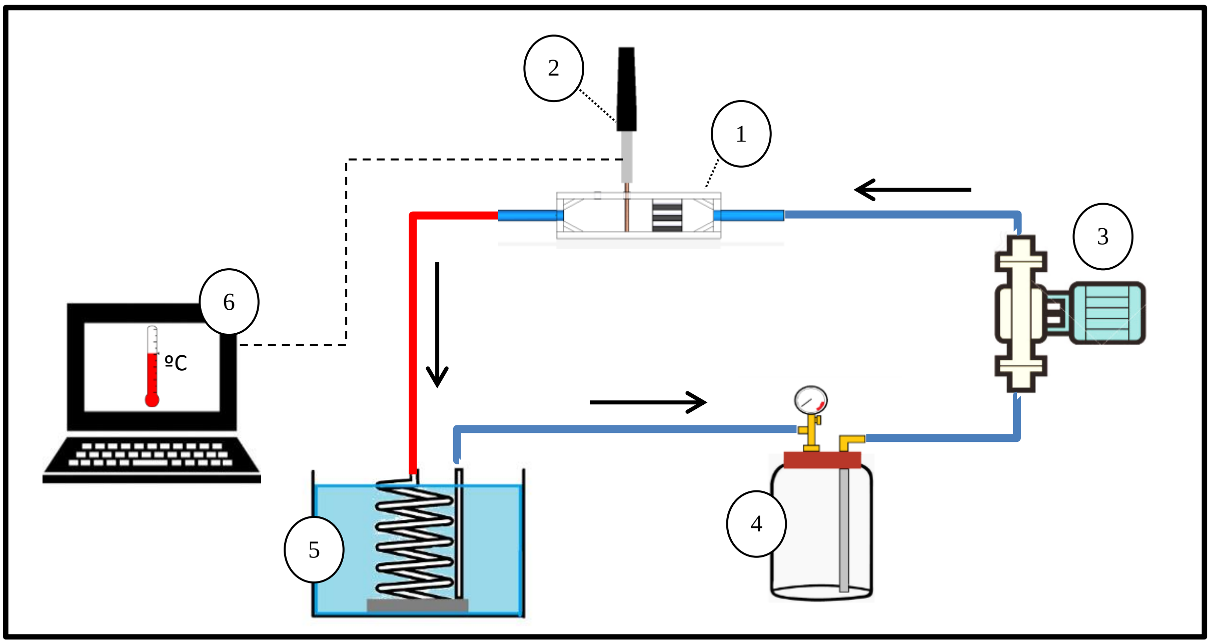

Figure 3. Circulation system. (1) Heating chamber; (2) heating unit; (3) Peristaltic pump; (4) Reservoir; (5) Cooling unit; (6) Computer for data acquisition.

2.3 Nanofluids and Final Test Conditions

The silver nanoparticles used in the study had a spheroidal shape with 20 nm of average diameter and were provided by TNS Nanotecnologia Ltda. During the experiments two concentrations of silver nanoparticles in solution of water and ethylene glycol (44/56 wt%) were used, as well as an electric field was applied in order to study the influence of the electrohydrodynamic effect on the convective heat transfer coefficient. Thus, 6 different test conditions were performed according to Tab. 2 and, after that, the dynamics viscosities of each nanofluids were measured. The flux was of 0.37 L/min of fluid and each test lasted 36 minutes.

Table 2. Final test conditions.

Condition	Fluid	Volumetric concentration (%)	Electric Field (kV/m)
1	ETG + $H_2O_{(l)}$		-
2	ETG + $H_2O_{(l)}$		Applied
3	ETG + $H_2O_{(l)}$	0.04	-
4	ETG + $H_2O_{(l)}$	0.04	Applied
5	ETG + $H_2O_{(l)}$	0.08	-
6	ETG + $H_2O_{(l)}$	0.08	Applied

After the tests were performed, an analysis was performed using an Energy Dispersive X-Ray Spectroscopy (EDS) to evaluate if deposition of nanoparticles in the cooper rod occurred.

2.4 Heat Transfer Coefficient

According to Incropera et al. (2008) and adopting some considerations needed in an inverse problem of heat transfer solution, the calculation of the distribution of temperatures throughout the length of the rod is given by the Eq. (1):

$$T(x) = T_\infty + (T_b - T_\infty).\frac{\cosh m(L-x)}{\cosh mL} \quad (1)$$

where T_∞ and T_b are the average temperature of the fluid and the fin base temperature, respectively. L is the length of the fin, m is a dimensionless parameter and x is the position where the temperature is been calculated.
Because the value of T_b and m were not known, MATLAB® 2013a software was used to provide these values. Knowing the value of m, the calculation of the convective heat transfer coefficient (h) is possible using the Eq. (2) :

$$m^2 = \frac{hP}{kA_{tr}} \quad (2)$$

where h is the convective heat transfer coefficient, P, A_{tr}, and k are the cross-section perimeter, the cross-section area and the thermal conductivity of the fin.

3. RESULTS AND DISCUSSION

Viscosity measurements were performed at temperatures from 11°C to 15°C as the mean temperatures of the fluids during the experiments were within that range. Figure 4 shows the comparison of the obtained values and it is noticed an increasing tendency of the viscosity when nanoparticle concentration is increased. The highest viscosity variation was of 20.3% at the temperature of 14°C for the nanofluid with 0.08 vol% when compared with the base fluid.

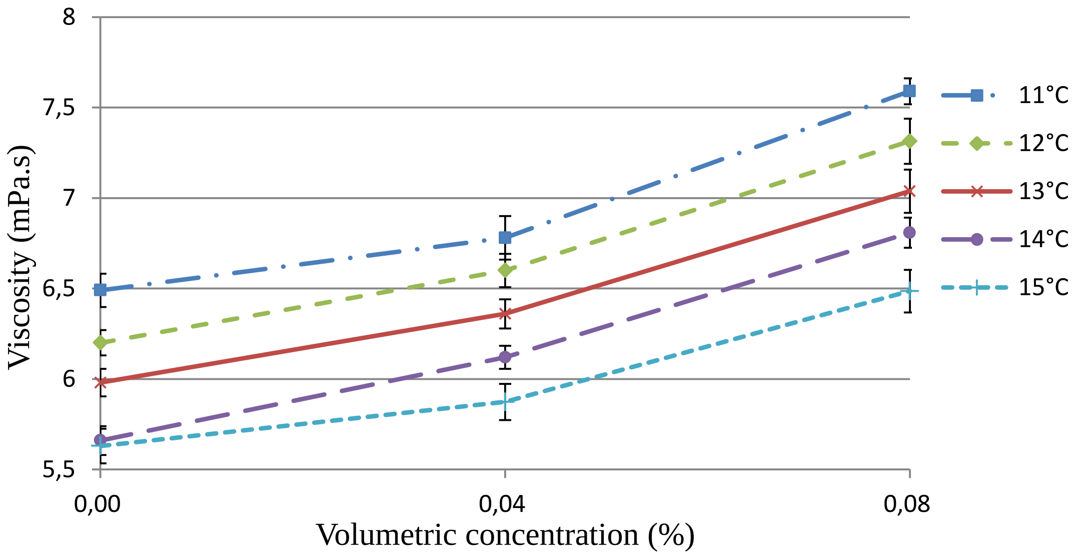

Figure 4. Viscosity variation for different nanoparticles concentrations and temperatures.

Analyzes using an Energy Dispersive X-Ray Spectroscopy (EDS) were performed to quantify the elements in the heated cooper surface. In this way, it could be evaluated if deposition occurred on the heated surface and also to quantify the percentage of each element deposited. As can be seen in Tab. 3, about 20% of the surface composition was silver at the positions T1 and T2, whereas in the lower position (T3), this value was of 3.52%. This difference can be justified by the fluid velocity gradient, since it was possible to verify a lower displacement of the fluid in the lower region. It is worth to mention that all silver deposited in the surface are nanoparticles from the nanofluid.

Table 3 –Mass fraction of elements identified on the heated surface at the position T1, T2 and T3.

Element	**C (%)**	**O (%)**	**Al (%)**	**Si (%)**	**Fe (%)**	**Cu (%)**	**Ag (%)**
Position T1	-	26.89	0.24	1.05	0.36	52.31	19.14
SD	-	6.15	0.11	0.02	0.09	3.91	9.88
Position T2	15.7	26.2	0.36	0.64	0.28	36.17	20.65
SD	5.13	3.05	0.17	0.35	0.2	9.71	0.81
Position T3	17.24	14.02	0.35	0.73	0.16	63.98	3.52
SD	8.73	1.72	0.27	0.41	0.23	12.94	1.6

*SD: Standard Deviation

The presence of Al, Si and C on the cooper rod are justified by the sanding and polishing process that were carried out before the tests, considering that the sands were composed of silicon carbide (SiC) and the polishing paste composed of Al_2O_3.

With the values of Tb and m determined by the use of a computational program, the calculation of the convective heat transfer coefficient (h) became possible. Table 4 presents the heat transfer coefficient (h) and the experimental uncertainty which was calculated considering the methodology presented by Holman (1994). The calculated uncertainty of heat transfer coefficient varies from 18.23% to 23.01%.

Table 4 –Heat transfer coefficient value.

Condition	Heat Transfer Coefficient (h)
1	1055 ± 223
2	1146 ± 263
3	1083 ± 239
4	1169 ± 236
5	897 ± 163
6	955 ± 180

It is presented in Fig. 5 a comparison between the base fluid (h_0) and the heat transfer coefficient (h) from others conditions analyzed. It is observed that the addition of nanoparticles increased the value of h in 11% for condition 3. On the other hand, for condition 5, the value of h reduced 15%. For the conditions where the application of the electric field occurred it is possible to verify an increase of h always when compared with the similar condition without application of this effect.

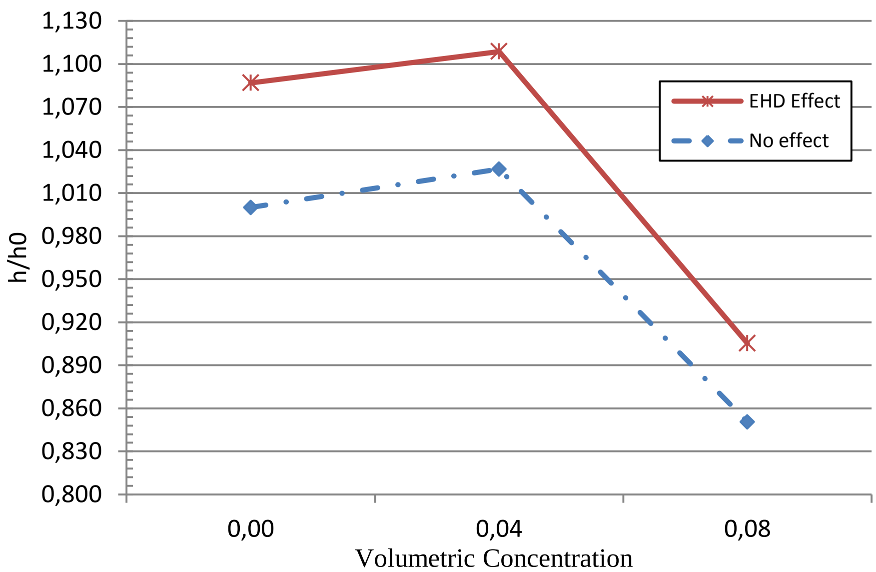

Figure 5. Variation of the heat transfer coefficient when compared with the base fluid.

Therefore, it is justified that the volumetric concentration of 0.08% altered the viscosity of the fluid affecting negatively the h. Further, with a higher concentration, there was an intensification of nanoparticle deposition, forming a barrier between fluid and heated surface, which contributed to the coefficient degradation. Nevertheless, the electric field application reduced the intensity of this degradation when compared with the same condition but without the electric field application.

4. CONCLUSIONS

As conclusion, it is evident that the interaction between nanoparticles and heated surface as well as the nanofluid stability are of fundamental importance. The nanofluid was favorable in the lowest concentration adopted and under electric field effect. This condition resulted in an increasing of 11% in the heat transfer coefficient value. At the highest concentration (0,08 vol%), the heat transfer coefficient value was reduced due to the combination of deposition on the heated surface and the increase in the nanofluid viscosity.

5. ACKNOWLEDGEMENTS

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