SHELL-AND-TUBE HEAT EXCHANGERS USING NANOFLUIDS

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Abstract
This study is a comparison of the thermophysical properties of the fluids conventional water and ethylene glycol with nanofluids Al2O3 and CuO immersed in water and glycol etilenio, and the other hand, demonstrate its feasibility for use in industrial heat exchangers. The purpose of this paper is to present this new class of fluid called nanofluid, analyze the behavior of the thermophysical properties of two nanofluids, nanofluid of alumina oxide and copper oxide. Also, checking the reduction in the proposed design of a shell-and-tube heat exchanger, hoping to find a good reduction in the use of this novel class of fluid. It was performed numerical simulations.

Keywords: *Nanofluid, Heat Transfer, Reduce Heat Exchangers*

1. INTRODUCTION

One of the most innovative science segments of today is nanotechnology, in view of its ability to impact across the board and significant production chain. Nanoscience enables the suggestions on initiatives and programs to develop competitive industrial, and seek consensus on opportunities and challenges and set goals and actions for sustainable development and the production chains in various industry segments.

A remarkable characteristic of nanofluids is that by the addition of small amount of nanoparticle, they show anomalous enhancement in thermal conductivity over 10 times more than the theoretically predicted. According to Eastman et al (Eastman et al. 2001) a 40% thermal conductivity increase in ethylene glycol is observed by adding only 0.3 vol.% of copper nanoparticles with a diameter smaller than 10 nm. A better understanding of the heat transfer process is crucial to improve efficiency in the industrial activities. Since Maxwell (1873) there have been registers of dispersed solid particles are used in the liquid but, was possible to use nanoparticles dispersed in the liquid. The particle size is important for stability and for increasing the thermal conductivity of the fluid.

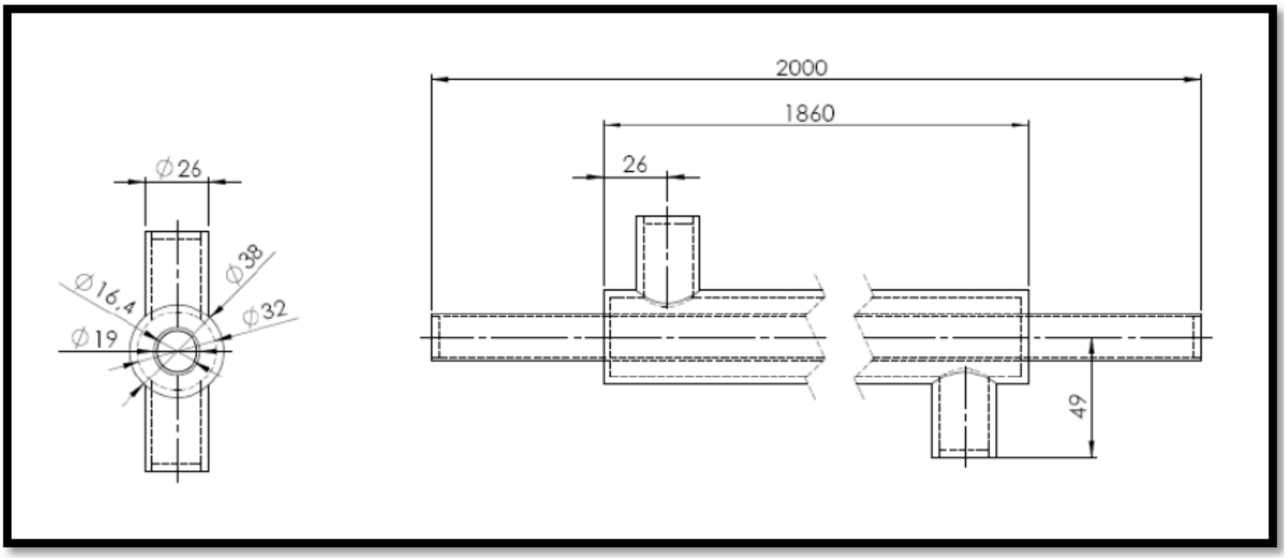

Fig 1. Geometry of the heat exchange using the nanofluids. (Guerrieri, 2010)

The principal goal of this study is to better understand the behavior of thermophysical properties of nanostructured materials in a heat exchanger, Fig. 1. Specially those involved in the phenomena of heat transfer. A simple geometry is chosen; a shell-and-tube heat exchanger with single pass to show the performance of nanoparticles immersed in fluid, emphasizing the structure, dimension and thermophysical properties, to simulate the heat transfer enhancement.

2. THEORETICAL FORMULATION

A remarkable characteristic of nanofluids is that by the addition of small amount of nanoparticle, they show anomalous enhancement in thermal conductivity over 10 times more than the theoretically predicted. According to Eastman et al (Eastman et al. 2001) a 40% thermal conductivity increase in ethylene glycol is observed by adding only 0.3 vol.% of copper nanoparticles with a diameter smaller than 10 nm.

Conventional fluids such as water, ethylene glycol and oil, are widely used in various branches of industry as coolants. These fluids have deficiencies among which include the low evaporation temperature, as water, and low thermal conductivity in the case of oils and ethylene glycol.

The addition of nanoparticles in the fluid changes the flow structure, so that besides increasing the thermal conductivity, chaotic motion, dispersion and fluctuation of the nanoparticles especially near the tube wall of a heat exchanger leads to an increase in the rate of energy exchange and increases heat transfer between the fluid and the tube wall. Furthermore, at high flow rates, the effects on dispersion and chaotic motion of nanoparticles enhance mixing fluctuations and changes in temperature profile to a flatter profile similar to turbulent flow and cause an increase in the coefficient of heat transfer. And in low Peclet number, a lower rate of heat transfer can be observed at low temperature flow and agglomeration of nanoparticles may exist in the flow nanofluid. Experiments on convection heat transfer of nanofluids were conducted by several research groups (Buongiorno 2006; Chein and Huang 2005; Etemad et al. 2006; Kim et al. 2004a; Said and Agarwal 2005; Xuan and Li 2003).

For a theoretical modeling, the nanofluid can be defined as a mixture consisting of a continuous base fluid component called “matrix” and a discontinuous solid component called “particles”, where the subscript “m” represent the base fluid matrix and the subscript “p” represent particles in base fluid.

According to the report of Argonne National Laboratory, the parameters that affect the thermal conductivity of nanofluid from experiments are 1-Particle volume concentration, 2-Particle materials, 3-Particle size , 4-Particle shape, 5-Base fluid material, 6-Temperature, 7-Additive and 8-Acidity.

Thus, the calculation of the effective density (ρ_e) and the specific heat effective (C_{pe}) of a nanofluid can be estimated based on the physical principle of the rule of mixture as in Eqs. 1-4.

$$\rho_e = \left(\frac{m}{V}\right)_e = \frac{m_m + m_p}{V_m + V_p} = \frac{\rho_m V_m + \rho_p V_p}{V_m + V_p} = (1 - v_p)\rho_m + v_p \rho_p \tag{1}$$

$$(\rho C_p)_e = \rho_e \left(\frac{Q}{m\Delta T}\right)_e = \rho_e \frac{Q_m + Q_p}{(m_m + m_p)\Delta T} = \rho_e \frac{(mC_p)_m \Delta T + (mC_p)_p \Delta T}{(m_m + m_p)\Delta T} \tag{2}$$

$$= \rho_e \frac{(\rho C_p)_m V_m + (\rho C_p)_p V_p}{\rho_m V_m + \rho_p V_p} = (1 - v_p)(\rho C_p)_m + v_p (\rho C_p)_p \tag{3}$$

So,

$$C_{pe} = \frac{(1 - v_p)(\rho C_p)_m + v_p (\rho C_p)_p}{(1 - v_p)\rho_m + v_p \rho_p} \tag{4}$$

2. THEORETICAL MODEL OF THE THERMAL TRANSPORT IN NANOFLUIDS

The tininess of nanoparticles or other nanostructures are responsible for improve the stability and the applicability of liquid suspensions, and increases the specific surface area (SSA) and thus the diffusion mobility of Brownian motion of nanoparticles.

Since Choi and Eastman found the so-called “anomalous” increase in thermal conductivity of nanofluids, many propositions have been made to better understand the phenomena involved. The Effective Medium Theory (EMT), derived by Maxwell, is used to explain the thermal conductivity enhancement of slurries and liquid suspensions. In his classical work, Maxwell assumed a very dilute suspension of spherical particles by neglecting the interactions between particles and then he solved Laplace equations for the temperature field beyond the particles in two equivalent ways:

1) Assume a large sphere containing all the spherical particles with an effective thermal conductivity k_{eff} embedded in the base fluid with thermal conductivity k_f; or

2) assume all the spherical particles with a thermal conductivity k_p embedded in the base fluid with a thermal conductivity k_f.

The two equivalent equations and by equating these two equations, Maxwell obtained the effective thermal conductivity of the suspension. Maxwell's model was adopted in Hamilton and Crosser, 1962 and later these EMT theories were modified by including the effects of particle shape, particle distribution, high particle concentrations, contact resistance and particle interactions (Granqvist and Hunderi 1978; Hasselman and Johnson 1987; Jeffrey 1973; Rayleigh 1892; Xue 2000).

Numerical analysis was performed in the Mathcad 14 software, due to simple and direct language, installed in a STi notebook with Pentium T3400, 2GB RAM and operating Windows Vista Home system.

As these are non conventional fluids was necessary to determine some thermophysical characteristics to perform the comparison. Thus we used the following equations:

For effective thermal conductivity (Hamilton and Crosser, 1962) as in Eq. 5.

$$k_{eff} = k_{bf}\frac{\left[k_p + (n-1)k_{bf} - \phi(n-1)\left(k_{bf} - k_p\right)\right]}{\left[k_p + (n-1)k_{bf} + \phi\left(k_{bf} - k_p\right)\right]} \tag{5}$$

where, ϕ is volume ratio of nanoparticles in nanofluid, k_p is the thermal conductivity of the particle, K_{bf} is the thermal conductivity of the base fluid and n is an empirical value defined by the shape of the particle. In this case, considering the spherical particle, $n = 1$, can be rewritten (Maxwell, 1873), as in Eq. 6.

$$k_{eff} = \frac{k_p + 2k_{bf} + 2\phi(k_p - k_{bf})}{k_p + 2k_{bf} - \phi(k_p - k_{bf})}k_{bf} \tag{6}$$

For effective specific mass, Eq. 7 states

$$\rho_{eff} = \rho_p\phi + \rho_{bf}(1-\phi) \tag{7}$$

where, ρ_p is the specific mass of the particle and ρ_{bf} is the specific mass of base fluid.

For effective specific heat, see Eq. 8.

$$Cp_{eff} = \frac{\rho_{bf}Cp_{bf}(1-\phi) + \rho_p Cp_p\phi}{\rho_f(1-\phi) + \rho_p\phi} \tag{8}$$

where, Cp_p and Cp_{bf} are respectively the specific heat of the nanoparticle and the specific heat of the base fluid.

For effective viscosity (Brinkman, 1952), Eq. 9.

$$\mu_{eff} = \frac{\mu_{bf}}{(1-\phi)^{2,5}} \tag{9}$$

where, μ_{bf} is the viscosity of the base fluid.

To calculate the heat exchanger a comparison of dimensions is performed. For that, the required assumptions are:

i. Water is the hot fluid and the cold fluid consists of three different fluids (water as base fluid or aluminum oxide nanofluid or copper oxide nanofluid);
ii. The hot fluid is stored in a reservoir, the water line is at a height of 1 meter from the inlet of the heat exchanger;
iii. For the hot fluid, the inlet fluid temperature should be 90°C and the outlet should be 82°C.
iv. The velocity of the cold fluid was considered to take better advantage of the system, approximately 2.9 m / s.
v. For the cold fluid the inlet fluid temperature should be 26°C and the outlet should be 31°C.

For a flow in turbulent regime, the heat transfer coefficient can be calculated from the Dittus-Boelter correlation, as in Eq. 10.

$$h = 0,023 \cdot \frac{k}{d} \mathrm{Re}^{0,8} \mathrm{Pr}^{n} \quad (10)$$

where, k is the thermal conductivity, d is the diameter, Re is Reynolds number, Pr is de Prandtl number and n is a constant number that is worth: 0.3 - cooling fluid and 0.4 - heating fluid.

3. RESULTS AND DISCUSSIONS

The thermal conductivity of nanofluids increases linearly with increase in the temperature of nanofluids for a particular volume concentration as shown in Fig. 2. Figures 2 and 3, demonstrate the overall heat exchange coefficient. and show a comparison between the base fluid and nanofluid.

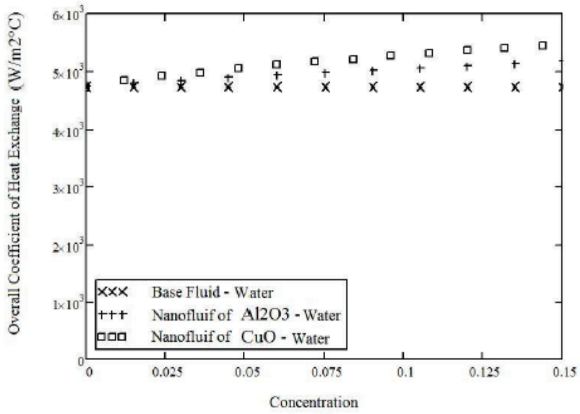

Figura 2. Overall coefficient of heat exchange with the water-based nanofluids. (Guerrieri, 2010)

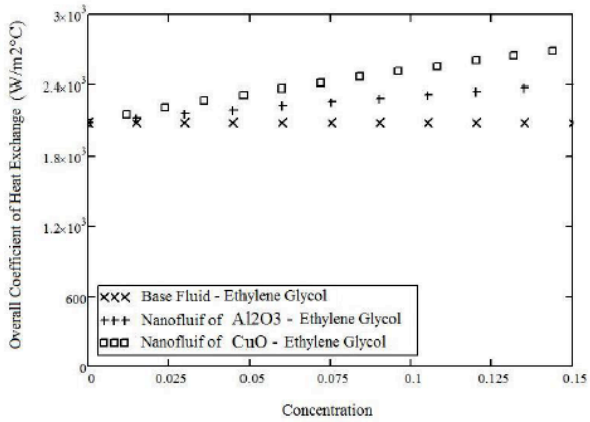

Figura 3. Overall coefficient of heat exchange with the ethylene glycol base nanofluids. (Guerrieri, 2010)

The nanofluids of high particle concentration have shown higher thermal conductivity as is evident from the Fig. 2 and 3. Both particle loading and Nanofluid temperature are dependent on thermal conductivity of CuO Nanofluids. The propylene glycol based nanofluids have low thermal conductivity compared to water based Nanofluids. The effective length of the heat exchanger using the base fluids without particles is submerged 2.166 m.

Table 1. Reduction with water-based nanofluid.

Concentration	Useful Length (m)		Reduction (%)	
	Al_2O_3	CuO	Al_2O_3	CuO
0	2,17	2,17	0	0
0,05	2,094	2,032	3,3	6,2
0,10	2,037	1,944	6	10,3
0,15	1,991	1,88	8,1	13,2

Table 1. Reduction with ethylene glycol base nanofluid.

Concentration	Useful Length (m)		Reduction (%)	
	Al_2O_3	CuO	CuO	Al_2O_3
0	4,92	4,92	0	0
0,05	4,66	4,41	5,3	10,4
0,10	4,45	4,06	9,6	17,5
0,15	4,28	3,80	13,1	22,7

Results are also compared with other correlations and useful lenght of the heat excheger using water based Al_2O_3 nanofluids and are shown in the Fig.4. It can also be observed from the figure that more enhancements in the thermal conductivity is observed at higher temperatures than at lower temperatures of nanofluids.

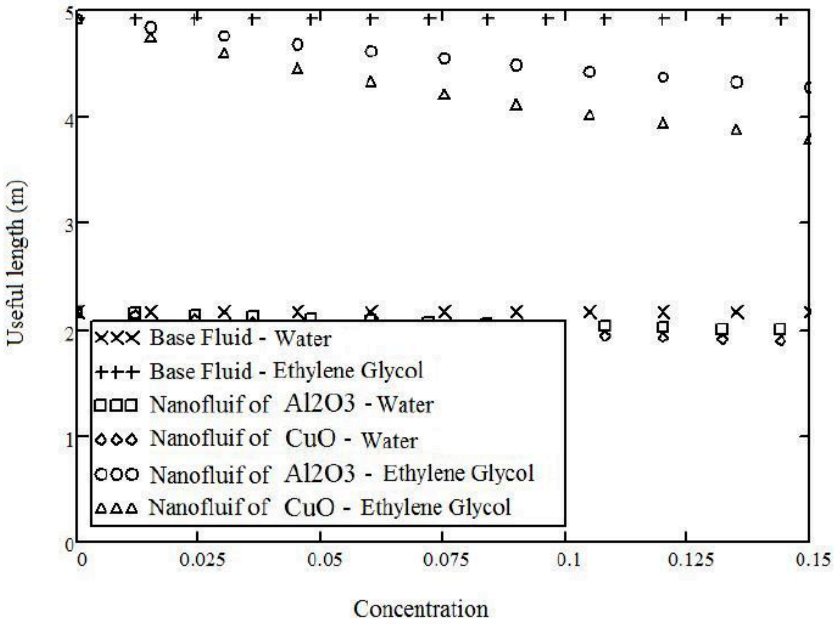

Figura 4. Useful length of the heat exchanger.

4. CONCLUSION

This study aimed to present a new fluid, and the feasibility of its use. The nanofluid is revolutionizing the concept of heat exchange, making researchers teams from around the world to rethink about this concept to enable their use in industrial equipment such as: refrigerators, heaters, among others.

The methods used in this work, been conventional methods, however, a study that has to check if in fact the conventional methods are suitable for the use of this novel class of fluid.

The nanofluids of high particle concentration have shown higher thermal conductivity as is evident from the Fig. 2 and 3. Both particle loading and Nanofluid temperature are dependent on thermal conductivity of CuO Nanofluids. The propylene glycol based nanofluids have low thermal conductivity compared to water based Nanofluids.

A significant modification of thermophysical properties due to emulsion nanostructured particles in the fluid based, in this case water and ethylene glycol, provided a significant decrease in the dimensioning of the heat exchanger. In fact this new technology demonstrate future commitments, however, makes clear the need to study more deeply about this, because without doubt is a kind of fluid, which will provide a revolution, making the heat exchangers in ever smaller dimensions.

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6. RESPONSIBILITY

The authors are the only responsible for the printed material included in this paper.