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THEORETICAL ANALYSIS OF ALUMINA-WATER NANOFLUIDS FLOWING IN HORIZONTAL TUBES

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Abstract. *This paper presents a theoretical analysis of energetic viability of use of Al_2O_3 nanoparticles dispersed in water as heat transfer fluids. The experimental results used in this analysis were obtained from an experimental work from the literature where the transport properties such as thermal conductivity and viscosity were really measured. With these experimental data, the pumping power of the base fluid and the nanofluid were obtained, and consequently the relative pumping power, which was compared with the relation of the heat transfer of nanofluid and the base fluid. This comparison was conducted at the same flow conditions, such as mean velocity. The results show that the use of this kind of nanofluid is not interesting, since the increase in pumping power is more significant than the enhancement of the heat transfer coefficient. The results of heat transfer coefficient for nanofluids presented higher values in relation to the base fluid just when the comparison is made using the Reynolds number.*

Keywords: *Heat Transfer coefficient, Alumina, numerical, Nanofluid, Horizontal tubes*

1. INTRODUCTION

The research on improvement of the thermal properties of the fluids for heat transfer takes a long time. Maxwell (1873) had already proposed a model to estimate thermal conductivity of spherical micrometer particles in suspensions. His model predicts an increase on thermal conductivity with volumetric concentration of the particles in suspension. Although, the use of this kind of suspensions has many problems as low stability, high augmentation in pump power and wall erosion. Nowadays, with the improvement in manufacturing process, it has been possible to use nanometer particles instead micrometer particles, to make suspensions in base fluids. These suspensions did not show the same problems listed above. These suspensions were denominated as nanofluids by Choi (1995).

The nanofluid research has been showed very promising field, mainly due to the possibility to enhance the capacity of heat transfer of the conventional fluids (such as water and oil), since they have very poor thermal conductivity compared to the metals. The great interest of the scientific researches in this field can be seen in Fig. (1), showing growth of publications involving nanofluids in heat transfer area over the years, taking into account just papers in journals and conferences.

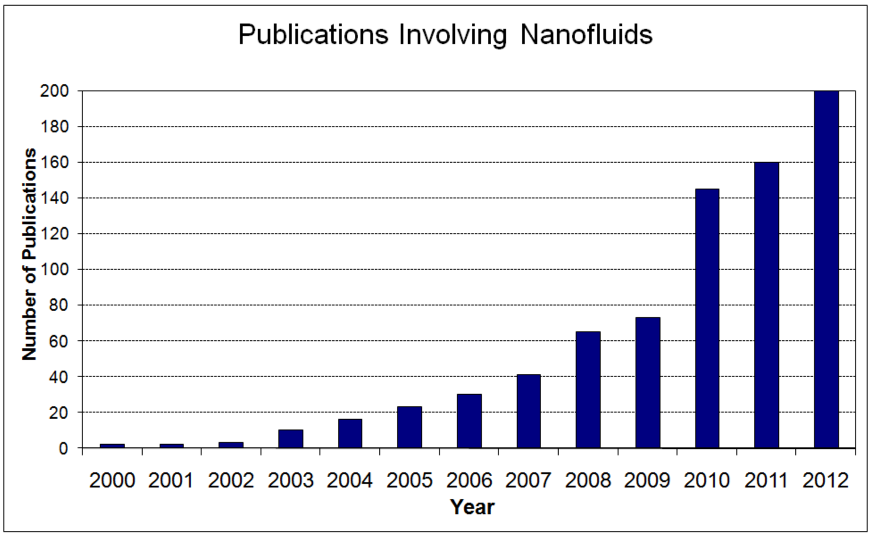

Figure 1 – Growth of publications involving nanofluids on years

The first researches involving thermal properties of nanofluids appeared in 90's. Masuda *et al.* (1993) reported an increase of 20% in the effective thermal conductivity, for 4.3% volumetric concentration of Al_2O_3 in water. Lee *et al.* (1999) obtained a maximum augmentation close to 20% on thermal conductivity of CuO in ethylene glycol for 4%

volumetric concentration. Eastman *et al.* (2001) reported an increase in 40% in thermal conductivity using a nanofluid with volumetric concentration of Cu close to 0.3% in ethylene glycol, relative to pure ethylene glycol. Yang et al. (2005) obtained an increase of 56% in thermal conductivity using 2.5% weight concentration of graphite in a commercial automatic transmission fluid (ATF).

Several authors have found that the friction factor of nanofluids is as similar as the friction factor of the base fluids (water, oils, etc.). These results revealed that for hydrodynamic behavior nanofluids can be treated like a single phase fluid. Williams et al. (2008) obtained in their experiments that the pressure loss behavior of the alumina-water and zirconia-water nanofluids in fully developed turbulent flow can be predicted by means of the traditional correlation, using for example, Blasius relation for the friction factor. Xuan and Li (2003) obtained that the friction factor of copper-water nanofluids was almost equal to the friction factor of water, which can be predicted by conventional correlations. Liao and Liu (2009) performed experiments of the turbulent nanofluids of multi-wall carbon nanotubes (MWNTs)-water and they obtained that the friction factor of these nanofluids were well correlated with the relation of friction factor's Nikuradse.

Many researches in convective heat transfer using nanofluids have shown an augmentation of convective heat transfer coefficient compared with their respective base fluids. Pak and Cho (1998) reported an increase of 45% and 75% on convective heat transfer coefficient of water, for alumina-water nanofluid with respectively 1.34% and 2.78% volumetric concentrations. Yang et al. (2005) obtained a maximum increase of 22% on heat transfer coefficient of ATF for a dispersion of 2.5% weight concentration of graphite-ATF. Most of the results concerning heat transfer using nanofluids are very optimistic, however many of these results do not express the real advantage in the use of nanofluids.

The goal of this work is to perform an energy analysis of the use of alumina-water nanofluids, based on the experimental results obtained by Pak and Cho (1998). This analysis aims to compare the heat transfer enhancement and the energy required to pump the nanofluids at the same Reynolds number. It is important to observe that the results showing an increase in terms of heat transfer of nanofluids are not enough to indicate their viability.

Nomenclature

Nu	Nusselt number (hD/k)
f	Friction factor, dimensionless
Re	Reynolds number (VD/ν)
Pr	Prandlt number (ν/α)
L	Length of the tube, m
V	Mean velocity, m s^{-1}
D	Diameter of the tube, m
h	Heat transfer coefficient, W m^{-2} K^{-1}
k	Thermal conductivity, W m^{-1} K^{-1}
c_p	Specific heat, J kg^{-1} K^{-1}
Δp	Pressure drop, N m^{-2}
	Pumping power, W
	Volumetric flow, m^3
Greek symbols	
α	Thermal diffusivity
ν	Molecular cinematic viscosity, m^2 s^{-1}
μ	Molecular dynamic viscosity, kg m^{-1} s^{-1}
φ	Volumetric concentration, %
ρ	Density, kg m^{-3}
Subscript	
nf	Nanofluid
bf	Base Fluid
r	Relative

2. THEORETICAL ANALYSIS

Pak and Cho (1998) measured the thermo-physics properties of the alumina-water nanofluids and performed experiments on turbulent flow of these nanofluids inside a tube with heat flux on the wall. They obtained the heat transfer coefficient and the Nusselt number in each flow condition. They correlated their experimental data of Nusselt number to alumina-water nanofluids, Eq. (1); it has a similar form of Dittus-Boelter correlation, Eq. (2). They also

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obtained a friction factor to the nanofluids that were compared with the values of friction factor of the Kays correlation, Eq. (3), and this comparison showed good agreement.

$$\mathrm{Nu}_{nf} = 0{,}021\,\mathrm{Re}_{nf}^{\ 0.8}\,\mathrm{Pr}_{nf}^{\ 0.5} \tag{1}$$

$$\mathrm{Nu}_{bf} = 0{,}023\,\mathrm{Re}_{bf}^{\ 0.8}\,\mathrm{Pr}_{bf}^{\ 0.4} \tag{2}$$

$$f = 0{,}312\,\mathrm{Re}^{-0.25} \qquad 5\mathrm{x}10^3 < \mathrm{Re} < 3\mathrm{x}10^4$$

$$f = 0.312\,\mathrm{Re}^{-0.25} \qquad 3\mathrm{x}10^4 < \mathrm{Re} < 10^6 \tag{3}$$

Where, Nu is Nusselt number, Eq. (4); Re is the Reynolds number, Eq. (5); Pr is the Prandtl number, Eq. (6); the subscript *nf* indicates nanofluid and the subscript *bf* indicates base fluid. When there was not subscript, the non-dimensional number can be calculated to both, base fluid and nanofluid, using their respective properties. In the Eqs. (4), (5) and (6), h is the heat transfer coefficient; D is the tube diameter; k is the thermal conductivity of the fluid; V is the mean velocity of the flow; v is the kinematic viscosity of the fluid and α is the thermal diffusivity.

$$Nu = \frac{hD}{k} \tag{4}$$

$$\mathrm{Re} = \frac{VD}{v} \tag{5}$$

$$\mathrm{Pr} = \frac{v}{\alpha} = \frac{c_p \mu}{k} \tag{6}$$

The pressure drop of the developed flow inside the tube can be calculated according Eq. (7) (Çengel, 2009), where f is the friction factor that can be estimated by Kays correlation, ρ is the specific mass of the fluid and L is the length of the tube.

$$\Delta p = \frac{f V^2 \rho L}{2D} \tag{7}$$

In the results of Pak and Cho (1998), the values of friction factor of alumina-water were as similar as the values of friction factor of the base fluid (water), then the pressure drop using alumina-water nanofluids can be related with the pressure drop using water, to obtain a relative pressure drop, Eq. (8), where the subscript r indicates that is a relation between the nanofluid and its base fluid.

$$\Delta p_r = \frac{\Delta p_{nf}}{\Delta p_{bf}} = \frac{\mu_r^{\ 2}}{\rho_r} \tag{8}$$

Using the relative pressure drop, where it is known that the pumping power is given by Eq. (9), can be obtained the relative pumping power, Eq. (10), where $\dot{V}$ is the volumetric flow and $\dot{W}$ is the pumping power required to flow the fluid.

$$\dot{W} = \dot{V} \cdot \Delta p \tag{9}$$

$$\dot{W}_r = \frac{\dot{W}_{nf}}{\dot{W}_{bf}} = \frac{\mu_r^{\ 3}}{\rho_r^{\ 2}} \tag{10}$$

The relation in Eq. (10) is very interesting since the increase in the required energy to pump the nanofluid is only a function of the properties of the nanofluid and the base fluid for the same Reynolds number. Therefore the relative pumping power is higher than the unit whether the Eq. (11) is valid.

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$$\mu_r > \rho_r^{2/3} \tag{11}$$

The relation between the correlation for the turbulent heat transfer coefficient for alumina-water nanofluids, proposed by Pak and Cho (1998), and the Dittus-Boelter correlation, is expressed in Eq. (12). From this equation and using the Nusselt number definition, Eq. (4), it was possible to obtain the relation between the heat transfer coefficient of alumina-water nanofluid and water, Eq. (13).

$$Nu_r = \frac{Nu_{nf}}{Nu_{bf}} = 0.91 \Pr_r^{0.5} \Pr_{bf}^{0.1} \tag{12}$$

$$h_r = \frac{h_{nf}}{h_{bf}} = 0.91 k_r \Pr_r^{0.5} \Pr_{bf}^{0.1} \tag{13}$$

Taking into account the Eq. (13) and Eq. (10), it is possible to verify, respectively, the enhancement of the heat transfer coefficient and the augmentation of the pumping power, using alumina-water nanofluids, obtained from Pak and Cho (1998).

3. RESULTS

To evaluate the heat transfer coefficient of the alumina-water nanofluids, it was used the experimental values of the nanofluids properties obtained by Pak and Cho (1998) and summarized in the Tab. 1.

Table 1. Experimental data of alumina-water nanofluids properties

φ (%)	k (W/m-K)	μ (kg/m-s)	ρ (kg/m^3)	c_p (J/kg-K)
1.34	0.675	1.40 x 10^{-3}	1035.73	4011.82
2.78	0.745	2.25 x 10^{-3}	1077.24	3841.56

Thus, from the data of Tab. 1, it was calculated the relative pumping power, using Eq. (10), and the relative heat transfer coefficient, using Eq. (13). Table 2 shows the relative heat transfer coefficient and the relative pumping power, comparing the enhancement of the heat transfer coefficient and the increase in pumping power in the use of alumina-water nanofluids and also a figure of merit (FOM), that is the ratio of the heat transfer coefficient and the pumping power, h_r $_r$, which is desired to be higher than the unit.

Table 2. Relative heat transfer coefficient and relative pumping power

φ [%]	h_r	$_r$	h_r $_r$
1.34%	1.43	3.60	0.40
2.78%	1.86	13.78	0.14

According to the Table 2, when the alumina-water nanofluid was used, it was clear that the cost of pumping power was higher than the enhancement in heat transfer. For example, when the volumetric concentration was 2.78 %, the relative pumping power was 7 times higher than heat transfer enhancement. Therefore, the use of alumina-water in turbulent flow inside the tube with heat transfer does not represent an advantage.

Figure 2 shows a comparison between the heat transfer coefficient and mean velocity, using Dittus-Boelter correlation for water and Pak and Cho correlation for alumina-water nanofluids. Figure 3 shows the comparison between the heat transfer coefficient of alumina-water nanofluids and base fluid at the same Reynolds number and Fig. 4 shows the comparison between the heat transfer coefficient of alumina-water nanofluids and water at the same mass flow rate.

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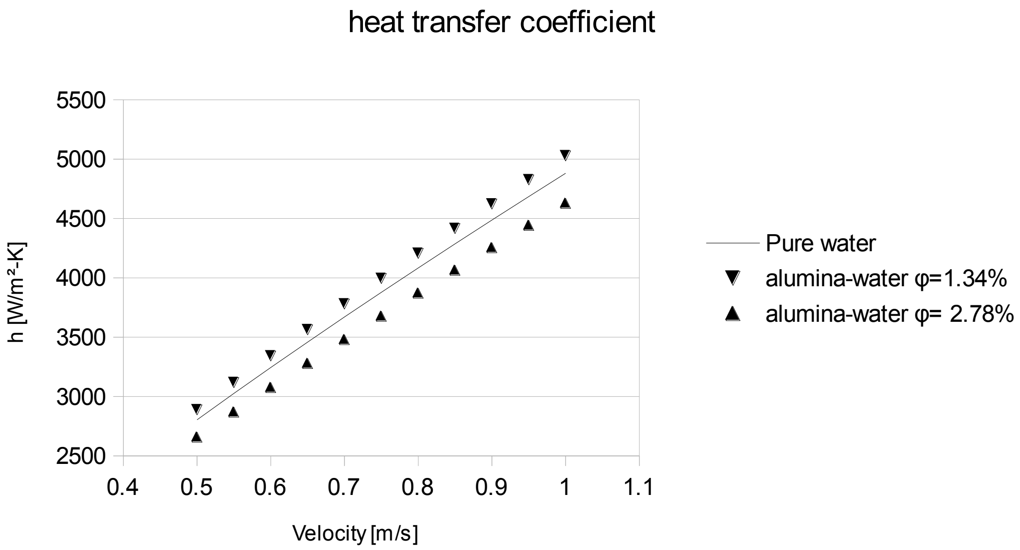

Figure 2. Comparison between heat transfer coefficient alumina-water nanofluids and water at the same mean velocity

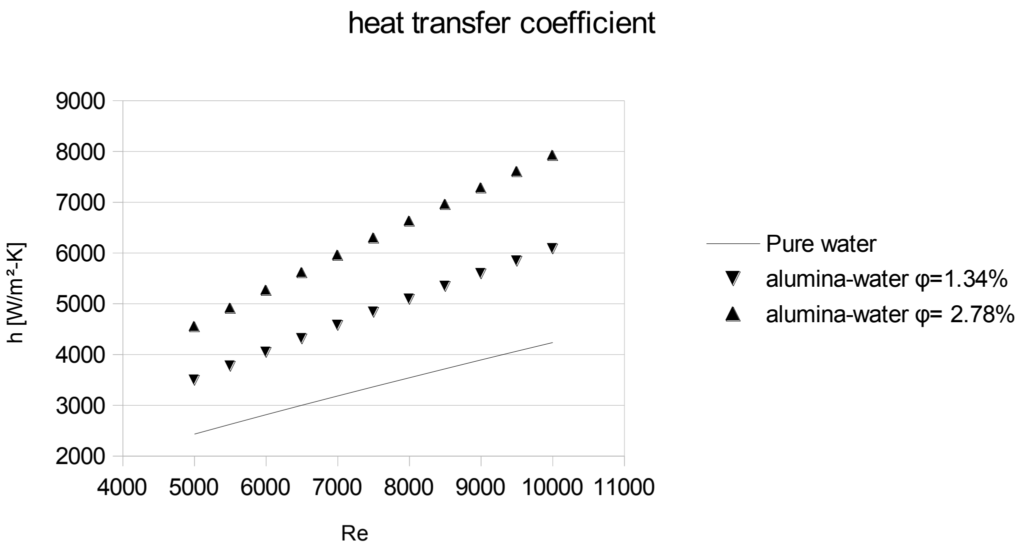

Figure 3. Comparison between heat transfer coefficient alumina-water nanofluids and water at the same Reynolds number

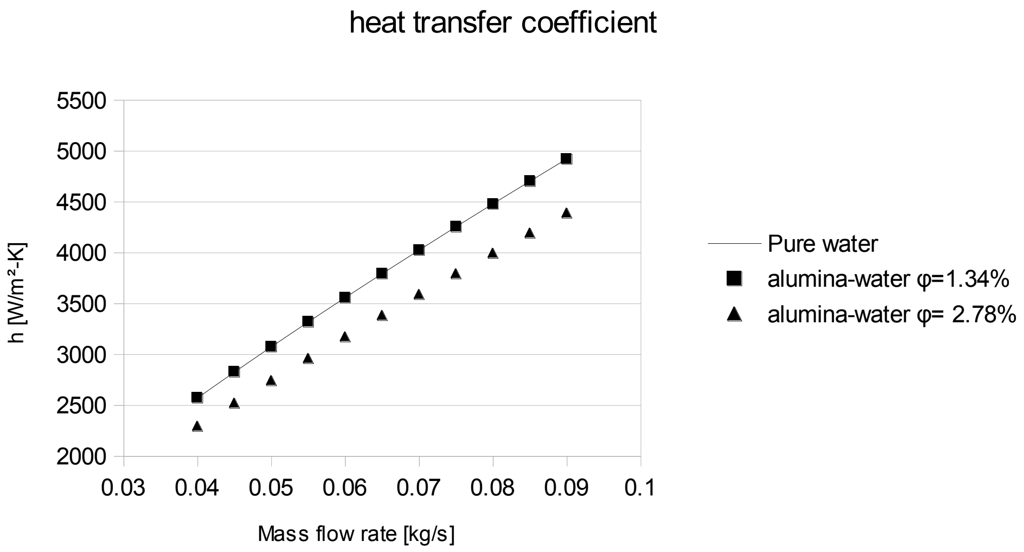

Figure 4. Comparison between heat transfer coefficient alumina-water nanofluids and water at the same mass flow rate

As can be seen, only in the comparison using Reynolds number, the heat transfer coefficient for alumina-water is significantly higher in relation to the water, Fig. 3. In the literature this comparison is often found without taking into account the behavior of pressure drop. In these conditions, this comparison shows an enhancement when alumina-water nanofluids are used. However, this trend can leads a wrong conclusion, where the relative pumping power can be higher than the relative heat transfer coefficient. It must be clear that, others parameters ought to be used for this purpose.

4. CONCLUSIONS

In this paper, as explained, to show the viability of nanofluids, in general, it is necessary to make an analysis involving heat transfer coefficient and pressure drop, using a figure of merit (FOM), obtained from relative relation between, the heat transfer coefficient and pumping power. Several experiments, such as Pak and Cho (1998), Williams et al. (2008) e Xuan and Li (2003), have shown that alumina-water (or even other nanofluids) nanofluids presented the same behavior on friction factor, it mean that the relative pumping power can be estimated through only two properties of the alumina-water nanofluids (or even other nanofluids) and water for the same Reynolds number.

The results of nanofluids were not conclusive and more studies involving other conditions are necessary to show the viability of the use of nanofluids in replacement of the conventional heat transfer fluids, which were conducted only a heat transfer analysis.

5. ACKNOWLEDGEMENTS

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