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EXPERIMENTAL STUDY OF HEAT TRANSFER IN A DOUBLE PIPE EXCHANGER USING NANOFLUIDS: SOLAR APPLICATION

Thierry Maré [a*], Razvan Luciu [b], Ousmane Sow [c], Stephan van Vaerenbergh [d]

a* LGCGM, INSA de Rennes, IUT Saint Malo, 35043 Rennes, France
b LGCGM, INSA de Rennes , facultad Iasi Rounamia
c Laboratoire d'Energie Appliquée, Ecole supérieure Polytechnique, Dakar, Sénégal
d laboratory micogarvity Bruxelle Belgium

ABSTRACT

Recently, a new class of fluid made up of metal nano-particles in suspension in a liquid, called nanofluid, appeared. Some numerical studies have shown that these new fluids have a higher heat transfer performance, compared with the conventional liquids. In the present study, we have attempted to study, by experimentation, the thermal performances of a particular nanofluid composed of aluminum oxide ($\gamma Al2O3$) particles dispersed in ethylene glycol 30% for various concentrations ranging from 0 to 2 %. The experimental set up is a coaxial exchanger, which is destined to solar application, in which the heating liquid used is the nanofluid studied.

NOMENCLATURE

D	Tube diameter [m]
k	Conductivity [W/m k]
K	Conductance [W/K]
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
S	annular Section [m^2]
P	Perimeter [m]
D_h	Hydraulic diameter [m]
c	Specific capacity [J/kg K]
h	Convection heat transfer coefficient [W/m^2 K]
ρ	Density [kg/m^3]
Φ	Heat flux [W]
ϕ_v	Volumetric Concentration [%]
μ	Dynamic viscosity [kg/ms]
V	Velocity [m/s]

indices

f	cool fluid (water in annulus)
o	basic fluid
b	bulk
n	nanofluid
EG	Ethylene Glycol
m	nano particle

INTRODUCTION

Nanofluids, a two-phase mixtures composed of very fine particles in suspension in a continuous and saturated liquids (water, ethylene glycol, engine oil), may constitute a very interesting alternative for advanced thermal applications (Lee and Choi [1]; Chein and Huang [2]. It has been found that important heat transfer enhancement may be achieved while using nanofluids compared to the use of conventional fluids; furthermore, some oxide nanoparticles exhibit an excellent dispersion properties in traditional cooling liquids. In spite of their remarkable features, only few published results on nanofluids use in confined flow situations have been reported – see Daungthongsuk and Wongwises [3] for a partial review. Pak and Cho [4] and Li and Xuan [5] have provided the first empirical correlation for computing Nusselt numbers in laminar and turbulent tube flows using water-based nanofluids. Others considered the use of nanofluids in microchannel heat sinks (Chein and Huang,[2]). Recent author's works Maïga [6], Nguyen [7], Palm [8] and Roy [9] - have clearly confirmed the heat transfer enhancement due to nanofluids in tube flow and in radial flow between heated disks.

Research efforts were mostly concerned with the characterization of nanofluids thermal and physical properties, among which, a good proportion of works was of experimental nature and focused on the determination of effective thermal conductivities

In this work, we have experimentally measured the heat performance of ethylene glycol-based nanofluids, Al2O3 with 47nm particle-sizes, and this in heat exchanger to solar application condition.

Indeed, to reduce the fossil energy utilization and to save energy, the passive solar application is in constant progress in the world. The countries of the North develop this technology principally for sanitary warm water production ADEME [10], and the countries of the South use it for news technique of production of fresh water, Sow [11]. The problem of the countries of the North is to perform the incidental solar energy, either by an improvement of the solar collectors, or by the increase of the exchange surface, or by the optimization of the inclination and the orientation. The countries of the South are interested in the energy autonomy; it is to be told to decrease the consummation of energy of the pumps of circulation of fluid.

Whatever the objective (decrease the surface of exchange or the circulation pump flow), the solution can be brought by the thermal improvement of the performances of the coolant.

The idea of our study is to change the usual ethylene glycol by ethylene glycol - Al_2O_3 nanofluid.

In the present work, the thermal performances, Nusselt number and convection heat transfer are obtained for different volume concentration. The nanofluid is introduced in the inner tube of a coaxial heat exchanger for co and counter current configuration.

EXPERIMENTAL SET UP

The schematic representation of the system studied is presented figure 1. The interior diameter of the inside tube is D4 = 6 mm, The exterior diameter is D3 = 8 mm. The second tube has an inner diameter D2 = 16 mm, 2 mm thick (D1 = 18 mm). The heat exchanger is being a length of 680 mm.

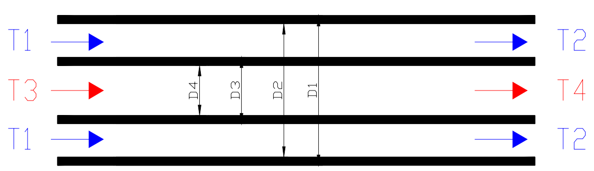


Figure 1 Schematic representation

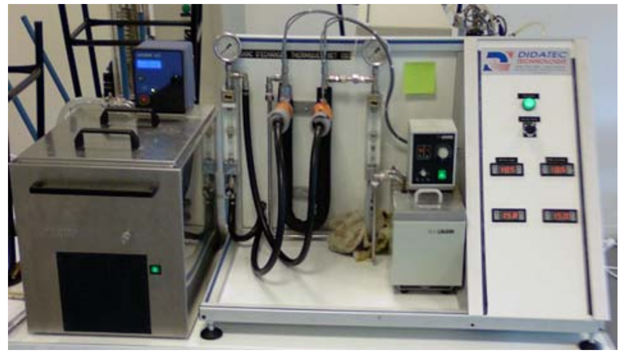
This exchanger is cover of an insulated sheath 4 cm thick with conductivity performance k =0.004 W/mK. These are U-Tubes and in inox made. (Picture 1).

The temperatures of the two fluids circulating respectively in the tube and in the annular space are controlled by Platinum type sunder, measuring 0.1 °C, placed at the entrances and exits.

The entrance of the tube and of the annular space (between the internal and external tube) are each linked to a thermal reservoir with a constant level.

The mass flow of the fluid entering into the tube as well as into the annular space is controlled by a miniature flow meter. These mass flows are measured at the exit with the aid of a graduated vase with an absolute uncertainty of 1 ml/s.

The average of heat transfer surface is 0,015 m².



Picture 1 Experimental set up

Water pump is used for fluid circulation inside and outside the inner tube with a maximum mass flow of 48 l/h. Two configurations (co and counter current) are possible.

To place our exchanger in a solar collector application, we put a cooling water fluid in the channel with temperature of 15 °C at the entrance and a constant mass flow of 30 l/h.

The heater fluid, inside the inner tube, is use to going from a solar collector; at temperature 16°c to 80°c.The flow is constant and around 30 l/h. The fluid used in the inner tube is composed of ethylene glycol 30% and water 70%, with nanoparticle concentration varying from 0% to 2%.

THERMAL PROPERTIES OF NANOFLUID

The nanoparticles used are aluminium oxide (γAl_2O_3) particles having the following characteristic: density $\rho_m = 3880$ kg/m^3, specific heat $c_m = 773$ J/kgK and thermal conductivity $k_m = 36$ W/mK; mean particle diameter is 47nm.

The following formula has been employed to relate the Ethylene Glycol pure data.

$$\rho_{EG30\%} = 0,3\rho_{EGpure} + 0,7\rho_{EG30\%}$$
$$c_{EG30\%} = 0,3c_{EGpure} + 0,7c_{EG30\%}$$
$$\mu_{EG30\%} = 0,3\mu_{EGpure} + 0,7\mu_{EG30\%}$$
$$k_{EG30\%} = 0,3k_{EGpure} + 0,7k_{EG30\%}$$

Density:

We will assume that the density and heat capacity of the aluminium oxide nanoparticles is constant over the entire range of temperature considered; however for ethylene glycol 30%, we will take into account its density variation with respect to the temperature. The following relation has been used to compute the nanofluid density and heat capacity:

$$\rho_n = (1-\phi_v)\rho_0 + \phi_v \rho_m$$

$$c_n = (1-\phi_v)c_0 + \phi_v c_m$$

Figure 2 shows the variation of the density of the nanofluid considered as function of the temperature as well as of the particle volume concentration.

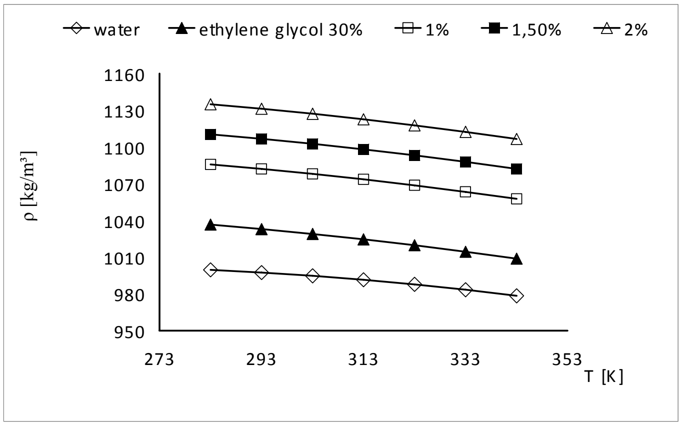


Fig. 2. Variation of nanofluid density with temperature

Figure 3 shows the variation of heat capacity of the nanofluid considered as function of the temperature as well as of the particle volume concentration.

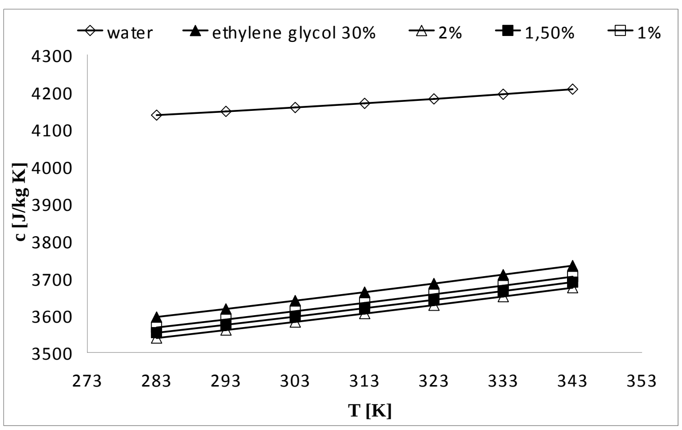


Fig. 3. Variation of nanofluid heat capacity with temperature

Dynamic viscosity:

The viscosity of the nanofluid can be estimated with the existing relations for the two phase mixture.

Drew and Passman introduced Einstein's formula for evaluating the effective viscosity. Fluid is containing a dilute suspension of small rigid spherical particles.

$$\mu_n = \mu_0(1-2{,}5\phi_v)$$

This formula is restricted for low volumetric concentration of particle, under 0.05%.

Brinkman proposed to extend Einstein's formula by:

$$\mu_n = \mu_0(1-\phi_v)^{2,5}$$

Other relations of effective viscosity of two phase mixture exist in the literature. Each relation has it own limitation and application. Some complex reaction has been observed by N Guyen [12].

Unfortunately results reveal that Brinkman's formula underestimates the few experimental data present in literature.

We have some experimental results in literature for viscosity of nanofluid with pure ethylene glycol. But it's seems there are no data for nanofluid with ethylene glycol 30%.

Finally we choose the polynomial approximation based on experimental data Nguyen [13], for pure. ethylene glycol- γ Al_2O_3 nanofluid.

$$\mu_n = (306\phi_v^2 - 0{,}19\phi_v + 1)\mu_0$$

We replace μ_0 by $\mu_{EG30\%}$

Figure 4 shows the variation of viscosity of the nanofluid considered as function of the temperature as well as of the particle volume concentration

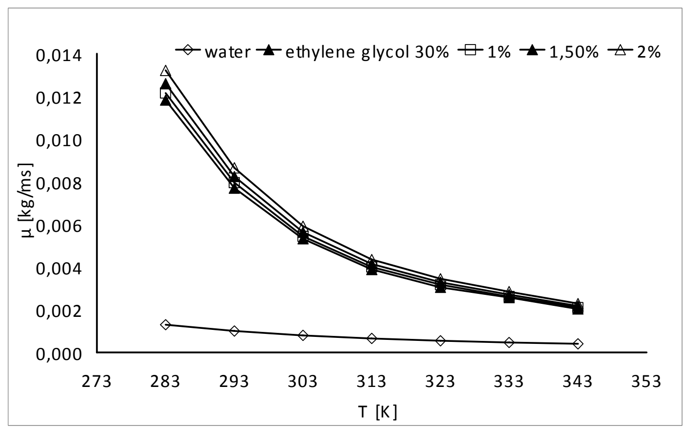


Fig. 4. Variation of nanofluid viscosity with temperate

Conductivity :

Lots of experimental researches have measured the thermal nanofluid conductivity and its evolution with temperature, but all data results are for the same nanofluid. It's because lots of parameters influence this thermal conductivity (concentration, shape and size of particles, dispersant, active or not mixed, agglomeration etc.). We adopted the Hamilton and Crosser [14] formula.

$$\frac{k_n}{k_0} = \frac{k_m + 2k_0 - 2\phi_v(k_0 - k_m)}{k_m + 2k_0 - \phi_v(k_0 - k_m)}$$

Figure 5 shows the variation of conductivity of the nanofluid considered as function of the temperature as well as of the particle volume concentration.

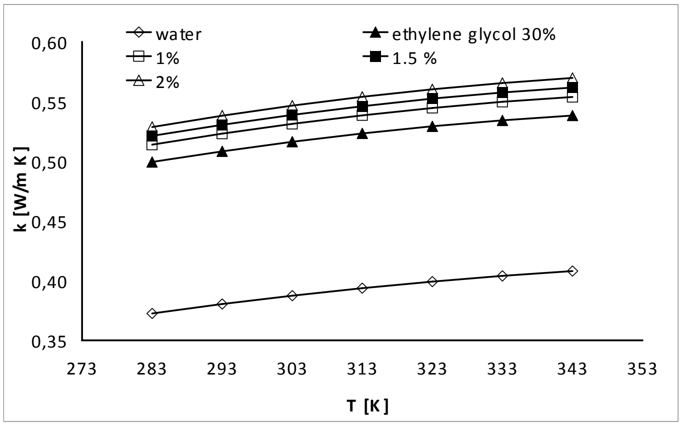


Fig. 5. Variation of nanofluid conductivity with temperature

Nusselt number and Heat flux

In the channel

Knowing temperature in and out, we can calculate the bulk temperature Tb

$$T_{bf} = \frac{T_2 + T_1}{2}$$

In our case we are in a short tube

$$\frac{L}{D_h} < 0.1 \mathrm{Re}\,\mathrm{Pr}$$

The Nusselt number for laminar flow in tube is done by Sider and Tates equation:

$$Nu = 1.86(\mathrm{Re}\,\mathrm{Pr}\, D_h / L)^{0.33}$$

With Reynolds Number

$$\mathrm{Re} = \frac{\rho V D_h}{\mu}$$

With hydraulic diameter

$$D_h = \frac{4S}{P} = D_2 - D_4$$

And Prandlt Number

$$\mathrm{Pr} = \frac{c_f \mu}{k_f}$$

And heat convection coefficient number for water hf:

$$h_f = \frac{Nu\, k_f}{D_h}$$

In the inner Tube

It is possible to determine the heat flow absorbed by the nanofluid by making the following relation:
In the channel

$$\Phi_{moy} = \frac{\Phi_f + \Phi_n}{2}$$

With

$$\Phi_f = m_f c_f (T_2 - T_1) \text{ and } \quad \Phi_n = m_n c_n (T_3 - T_4)$$

The heat lost through the walls; is obtained by calibration using water data for various flow rates and is around 5%.
Knowing the thermal power absorbed by the nanofluid and the bulk temperature in the inner and channel tube.

$$T_{bn} = \frac{T_3 + T_4}{2}$$

We can determinate the convection coefficient number for nanofluid h_n:

$$h_n = \frac{1}{\frac{\pi D_4 L}{K} - \ln(\frac{D_2}{D_4})\frac{D_4}{2k_{inox}} - \frac{1}{h_f}\frac{D_4}{D_2}}$$

With

$$K = \frac{\phi_{moy}}{T_{bn} - T_{bf}}$$

Nusselt number is:

$$Nu_n = \frac{h_n D_4}{k_n}$$

RESULTS

Table 1 shows the average of nanofluid Nusselt number obtained as function of the particle volume concentration, for co current and counter current.

Volumetric concentration	Co-current	Counter-current
0%	**3,78**	**3,85**
1%	**3,59**	**3,78**
1,5%	**3,58**	**3,61**
2%	**3,59**	**3,55**

Table 1. Average nanofluid Nusselt number in the inner tube

We can show that Nusselt average number is close to 3,66, the value for laminar flow fully developed in isothermal tube. This value is constant independently of concentration.

That would be interesting is to know how temperature distribution is and develop length of flow.

Figure 6 shows the variation of convection heat transfer coefficient of the nanofluid considered as function of the temperature as well as of the particle volume concentration, for co current and counter current

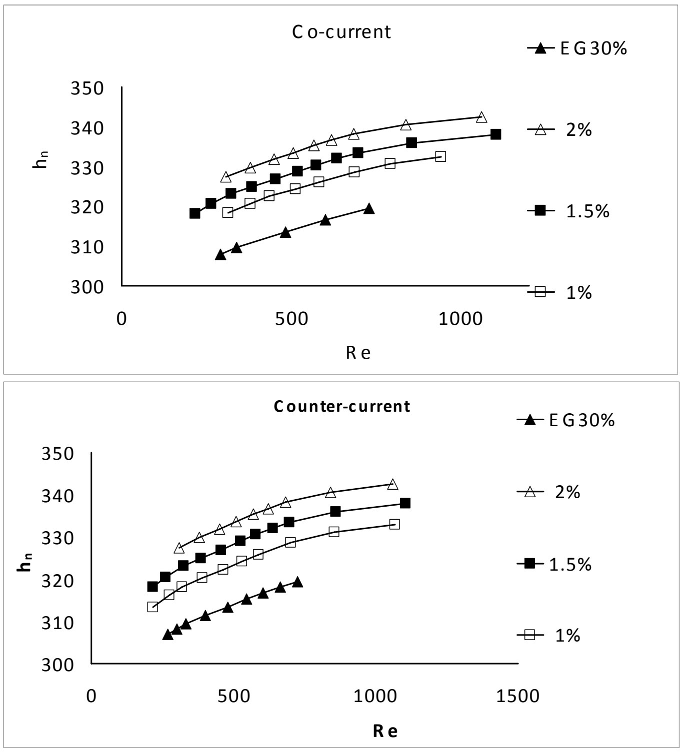


Fig. 6. Variation of convection heat transfer coefficient of nanofluid with Reynolds number

For a laminar flow, Nusselt number is independent of the Reynolds number, so the evolution of convection heat transfer coefficient is essentially due to the evolution of conductivity with temperature.
Convection increase with volume concentration, but difference is not significant between Co and counter current.

Figure 7 shows the variation of convective coefficient of the nanofluid considered as function as volume concentration, for co current and counter current

It is clearly observed, from figure 7, that for a given Reynolds number, the convective heat transfer coefficient has increased considerably with the particle volume concentration. On the other hand, for a same particle concentration, the fact of increasing the flow rate has also a great beneficial effect on the convective coefficient.

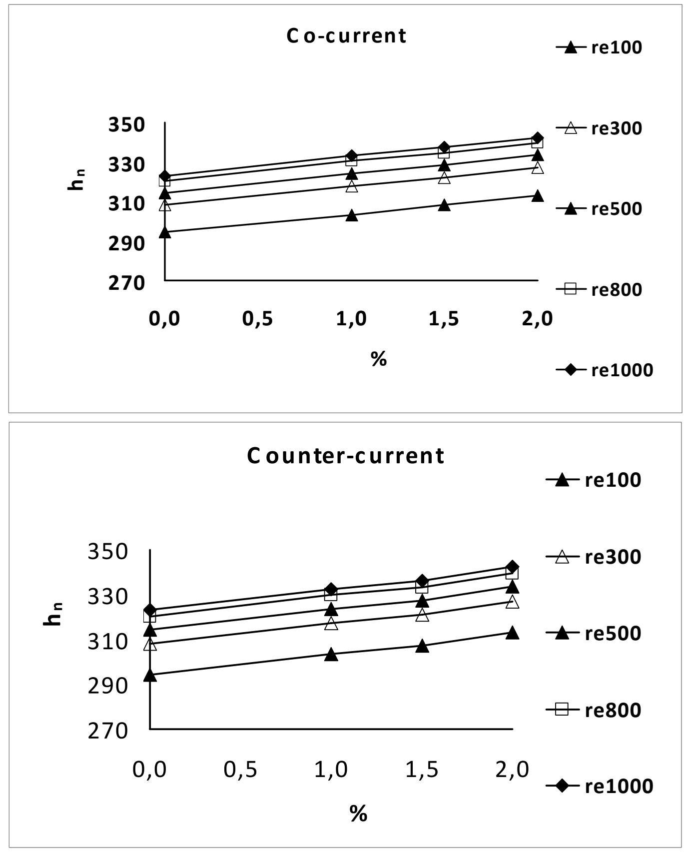


Fig. 7. Variation of convection heat transfer coefficient of nanofluid with volumetric concentration

Conclusions

An experimental study was carried out in order to investigate the heat transfer enhancement as provided by replacement of conventional fluid, water by a nanofluid with ethylene glycol inside a double pipe exchanger destined for solar application. The nanofluid used, which composed of aluminium oxide particles in suspension in ethylene glycol 30% solution, has been provided at various volume concentration ranging from 0% to 2%.
Experimental data have clearly shown that the use of such a nanofluid has provided a significant enhancement of heat transfer.
The heat transfer coefficient has been found to increase with augmentation of volume concentration as well with augmentation of flow rate. New measured data where also provided regarding the temperature dependence of the nanofluid viscosity and this for various particle concentrations.

Aknowledge : AUF support

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