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CONSTRUCŢII. ARHITECTURĂ

NUSSELT NUMBER AND CONVECTION HEAT TRANSFER COEFFICIENT FOR A COAXIAL HEAT EXCHANGER USING Al_2O_3–WATER pH=5 NANOFLUID

BY

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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 (γAl_2O_3) particles dispersed in water for various concentrations ranging from 0 to 4%. The experimental set up is a coaxial exchanger, which is destined to solar application, in which the heating liquid used is the nanofluid studied.

Key Words: experimental; nanofluid; Nusselt number.

1. 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 and Roy [8]) have clearly confirmed the heat transfer enhancement due to nanofluids in tube flow and in radial flow between heated disks.

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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 water-based nanofluids, Al_2O_3 with 47 nm 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 northern countries develop this technology principally for sanitary warm water production and the southern countries use it for news technique of production of fresh water. The problem of the northern countries 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 southern countries are interested in the energy autonomy; it is to be told to decrease the consumption of energy of the circulation of fluid pumps.

The idea of our study is to change the usual ethylene glycol by water–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 current configuration.

2. Experimental Set Up

The schematic representation of the system studied is presented Fig. 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 has a length of 150 mm.

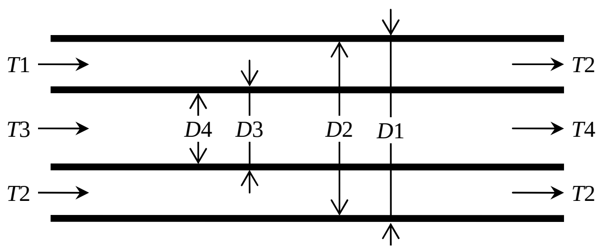

Fig. 1. – Schematic representation .

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 (Fig. 2).

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 flowmeter. 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 m^2.

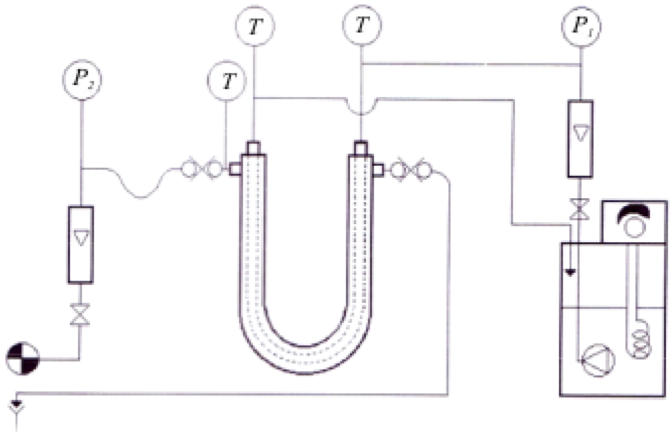

Fig. 2. – Experimental set up.

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 used to going from a solar collector; at a temperature of 16°C to 70°C . The flow is variable from 10 l/h to 40 l/h. The fluid used in the inner tube is composed of water, pH = 5, with Al_2O_3 nanoparticle concentration varying from 0% to 4%.

3. Thermal Properties of Nanofluid

The nanoparticles used are aluminium oxide (γAl_2O_3) particles having the following characteristic: density $\rho_m = 3,880\ \mathrm{kg/m^3}$, specific heat $c_m = 773\ \mathrm{J/kgK}$ and thermal conductivity $k_m = 36\ \mathrm{W/mK}$; mean particle diameter is 47 nm.

3.1. Density

We will assume that the density and heat capacity of the aluminium oxide nanoparticles is constant in the entire range of temperature considered. The following relations has been used to compute the nanofluid density and heat capacity

$$\rho_n = (1-\phi_v)\rho_0 + \phi_v \rho_m, \tag{1}$$

respectively

$$c_n = (1-\phi_v)c_0 + \phi_v c_m. \tag{2}$$

3.2. 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.

$$\mu_n = \mu_0(1-2,5\phi_v) \tag{3}$$

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

Brinkman proposed to extend Einstein's formula to

$$\mu_n = \mu_0(1-\phi_v)^{2.5}. \tag{4}$$

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 Nguyen [7].

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

Finally we choose the polynomial approximation based on experimental data Nguyen [7], for water–γAl_2O_3 nanofluid

$$\begin{aligned}\mu_n(1\%) = {} & 3.65785\times 10^{-11}T^4 - 4.88267\times 10^{-8}T^3 + 2.45398\times 10^{-5}T^2 - \\ & -5.510714\times 10^{-3}T + 0.467545089,\end{aligned} \tag{5}$$

$$\begin{aligned}\mu_n(2\%) = {} & 3.97752\times 10^{-11}T^4 - 5.30937\times 10^{-8}T^3 + 2.66844\times 10^{-5}T^2 - \\ & -5.992306\times 10^{-3}T + 0.508404721,\end{aligned} \tag{6}$$

$$\mu_n\,(3\%) = 4.5148\times10^{-11}T^4 - 6.02656\times10^{-8}T^3 + 3.02889\times10^{-5}T^2 - \\ -6.801744\times10^{-3}T + 0.577079809, \tag{7}$$

$$\mu_n\,(4\%) = -4.38576\times10^{-9}T^3 + 4.44807\times10^{-6}T^2 - \\ -1.513857\times10^{-3}T + 0.173517495. \tag{8}$$

Fig. 3 shows the variation of viscosity of the nanofluid considered as function of the temperature as well as of the particle volume concentration.

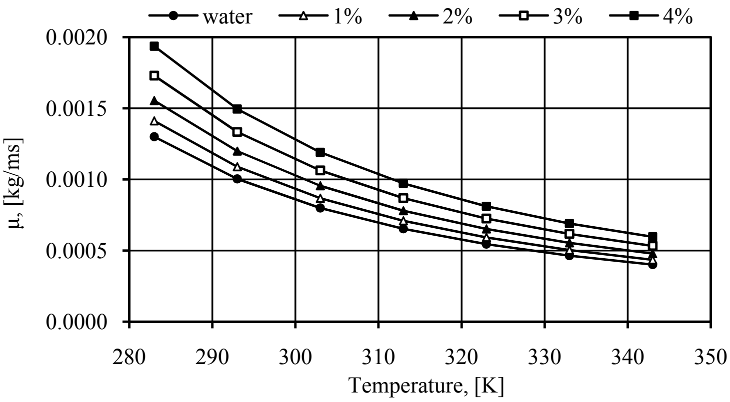

Fig. 3. – Variation of viscosity.

3.3. 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 use following experimental finally (Fig. 4), were measure conductivity instrument is KD2 by Decagon Devices Inc., with 8% precision. We heat adiabatic water tank and put nanofluid in an aluminium tank inside. So control nanofluid temperature varies from 5°C to 50°C . All the nanofluid is mixed between each measure.

The variation of conductivity of the nanofluid, considered as function of the temperature as well as of the particle volume concentration, is shows in Fig. 5.

Results data we put in the Nusselt equation are

$$\lambda_n\,(1\%) = -7.29423\times10^{-6}T^2 + 5.851204\times10^{-3}T - 0.468564118, \tag{9}$$

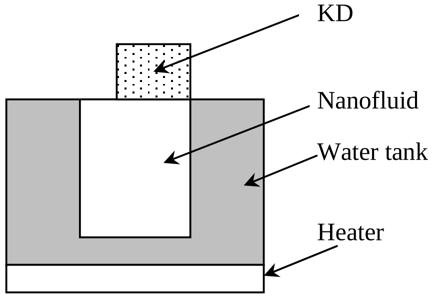

Fig. 4. – Conductivity experimental set up.

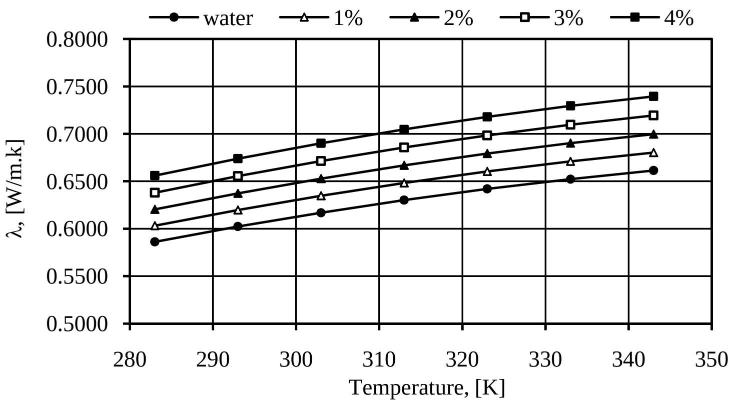

Fig. 5. – Variation of conductivity.

$$\lambda_n\,(2\%) = -7.49502 \times 10^{-6}T^2 + 6.011645 \times 10^{-3}T - 0.480642606, \tag{10}$$

$$\lambda_n(3\%) = -7.6996 \times 10^{-6}T^2 + 6.175092 \times 10^{-3}T - 0.4929312, \tag{11}$$

$$\lambda_n\,(4\%) = -7.90806 \times 10^{-6}T^2 + 6.341632 \times 10^{-3}T - 0.505435331. \tag{12}$$

4. Nusselt Number and Heat Flux

4.1. In the Channel

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

$$T_{bf} = \frac{T_2 + T_1}{2}. \tag{13}$$

The Nusselt number for laminar flow in tube is

$$\mathrm{Nu} = 3.66, \tag{14}$$

and heat convection coefficient number for water is

$$h_f = \frac{\mathrm{Nu} k_f}{D_h}, \tag{15}$$

with hydraulic diameter

$$D_h = \frac{4S}{P} = D_2 - D_4. \tag{16}$$

4.2. In the Inner Tube

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

$$\phi_{\mathrm{av}} = \frac{\phi_f + \phi_n}{2}, \tag{17}$$

with

$$\phi_f = m_f c_f (T_2 - T_1) \tag{18}$$

and

$$\phi_n = m_n c_n (T_3 - T_4). \tag{19}$$

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

$$T_{bn} = \frac{T_3 + T_4}{2}. \tag{20}$$

We can determinate the convection coefficient number for nanofluid:

$$h_n = \frac{1}{\frac{\pi D_4 L}{k} - \ln\left(\frac{D_2}{D_4}\right)\frac{D_4}{2\lambda_{\mathrm{inox}}} - \frac{1}{h_f}\cdot\frac{D_4}{D_2}}, \tag{21}$$

with

$$k = \frac{\phi_{\mathrm{av}}}{T_{bn} - T_{bf}}. \tag{22}$$

So Nusselt number is

$$\mathrm{Nu}_n = \frac{h_n D_4}{\lambda_n}. \tag{23}$$

5. Results

Fig. 6 shows the variation of Nusselt number of the nanofluid considered as function of the temperature as well as of the particle volume concentration. We can show that Nusselt average number increases with Reynolds number, and the value is between 1.2 to 2.2. That is less than Nusselt number of 3.66 for laminar flow in a tube.

The Nusselt number value decreases with volume concentration. We can note for Reynolds number up to 500, that Nusselt number average is around: 1.9 for 1%, 1.9 for 2%, 1.9 for 3%, 1.8 for 4%.

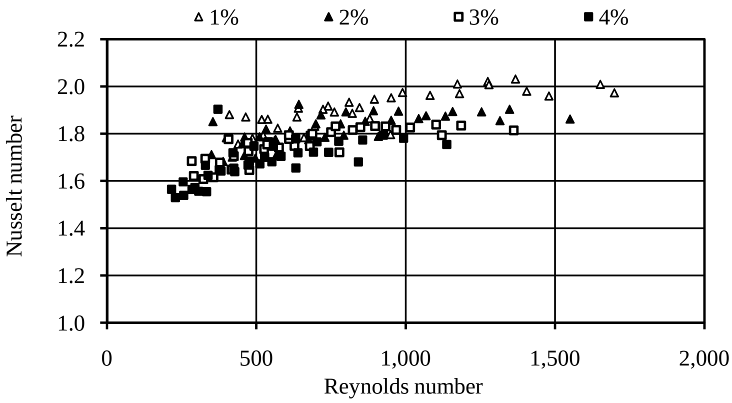

Fig. 6. – Variation of Nusselt number.

Fig. 7 shows the variation of convection coefficient of the nanofluid considered as function of the temperature as well as of the particle volume concentration. Convection coefficient increases with volume concentration, but difference is maximum 15% between 1% and 4% with high Reynolds number. That because when Nusselt number decreases with volume concentration, and conductivity increase in the same time.

6. 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 inside a double pipe exchanger destined for solar application. The nanofluid used, which composed of aluminium oxide particles in suspension in water (pH = 5), has been provided at various volume concentration ranging from 0% to 4%.

Experimental data have clearly shown a low Nusselt number due to the high conductivity number for this fluids, and high convection transfer coefficient.

New measured data where also provided regarding the surface temperature

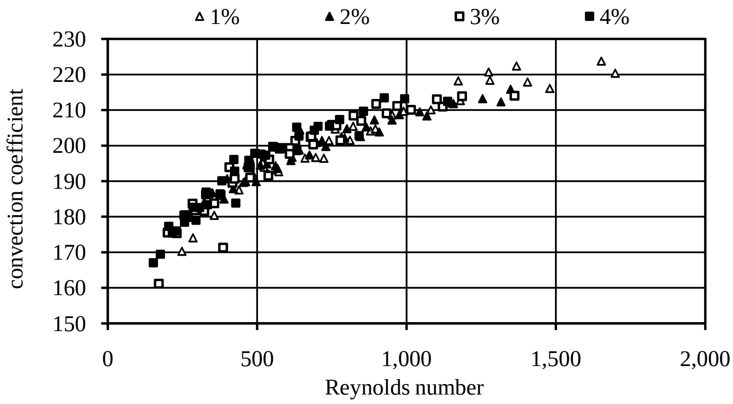

Fig. 7. – Variation convection.

of the tube and not taking account only the bulk temperature to have a best representation of heat transfer in a laminar flow with this kind of fluid.

Notations

D – tube diameter, [m];
λ – conductivity, [W/m.K];
Nu – Nusselt number;
S – surface, [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];

Indices

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

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NUMĂRUL NUSSELT ŞI COEFICIENTUL DE TRANSFER TERMIC CONVECTIV PENTRU UN SCHIMBĂTOR DE CALDURĂ COAXIAL UTILIZÂND NANOFLUIDE (Al_2O_3–APĂ pH=5)

(Rezumat)

O nouă clasă de fluide compuse din particule metalice în suspensie într-un lichid, numite nanofluide, a apărut recent. Câteva studii numerice arată că această nouă clasă de fluide posedă un potenţial remarcabil de transfer termic în comparaţie cu alte lichide convenţionale. Studiul experimental prezentat aici indică performanţele termice ale nanofluidului utilizat, compus din particule de oxid de aluminiu (γAl_2O_3) dispersate in apă pH = 5, în diferite concentraţii de la 0% la 4%.