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# HEAT TRANSFER STUDY IN A COAXIAL HEAT EXCHANGER USING NANOFLUIDS

BY

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**Abstract.** The heat transfer of nanofluids in a coaxial heat exchanger is studied numerically using a Computational Fluid Dynamics (CFD) approach. The present study indicates an increase of the thermal performances with 50% of nanofluids compared to water. The nanofluid is composed of aluminum oxide ($Al_2O_3$) particles dispersed in water for various concentrations ranging (1, 3 and 5%).

**Key words**: nanofluid; Nusselt number; Reynold's number; heat transfer.

## 1. Introduction

Convective heat transfer is very important for many industrial heating or cooling equipments. The heat convection can passively be enhanced by changing flow geometry, boundary conditions or by enhancing fluid thermo-physical properties. An innovative way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluid. M a x w e l l [1] showed the possibility of increasing thermal conductivity of a mixture by more volume fraction of solid particles. These fluids containing colloidal suspended nanoparticles, have been called *nanofluids*.

Several investigations revealed that nanofluid heat transfer coefficient could be increased by more than 20% also in the case of very low nanoparticles concentrations [2], [3].

A k b a r n i a and B e h z a d m e h r [4] reported a Computational Fluid Dynamics (CFD) model based on single phase model for investigation of laminar convection of water/$Al_2O_3$ nanofluid in a horizontal curved tube. In

their study, effects of buoyancy force, centrifugal force and nanoparticle concentration have been discussed.

Z e i n a l i *et al*. [5] proposed a dispersion model to account for the presence of nanoparticles in nanofluid. They showed that the dispersion and random movement of nanoparticles inside the fluid change the structure of flow field and led to heat transfer enhancement.

In this work we have numerically studied the heat performance of water-based nanofluids, $Al_2O_3$ with 10 nm particle-sizes, in a coaxial heat exchanger.

## 2. The Mathematical Model

The CFD approach uses a numerical technique for solving the governing equations for a given flow geometry and boundary conditions. The use of CFD reduces the number of necessary experiments and gives results, which would hardly be accessible by measurements.

The detailed flow field for the single-phase flow in a circular tube with constant wall temperature can be determined by solving the volume-averaged fluid equations, as follows:

a) *Continuity eq.*

$$\nabla\left(\rho\vec{V}\right)=0.$$

b) *Momentum eq.*

$$\nabla\left(\rho\vec{V}\vec{V}\right)=\nabla P+\nabla\left(\tau-\tau_t\right).$$

c) *Energy eq.*

$$\nabla\left(\rho\vec{V}C_pT\right)=\nabla\left(k\nabla T-C_p\rho\overline{v_t}\right).$$

In order to solve above-mentioned eqs. the thermo-physical parameters of nanofluids such as: density, viscosity, heat capacity, and thermal conductivity, must be evaluated. These parameters are defined as follows:

a) *Density and heat capacity*

The relations determined by P a k and C h o [6] have the form

$$\rho_n=\left(1-\phi_v\right)\rho_0+\phi_v\rho_m,\quad C_n=\left(1-\phi_v\right)C_0+\phi_vC_m.$$

b) *Thermal conductivity*

The effective thermal conductivity of a mixture can be calculated using the relation of M o h o r i a n u and A g o p [7]

$$\frac{k_{nf}}{k_f} = 1 + 0.043 \frac{k_p \varepsilon_1}{k_f \left(1 - \varepsilon_1\right)},$$

where we consider that $r_f / r_p \cong 0.043$ and $k_{\text{eff}} = k_{nf}$ .

c) *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

$$\mu_n = \mu_0 \left(1 - 2.5\phi_v\right).$$

Fluid is containing a dilute suspension of small rigid spherical particles.

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

Brinkman proposed to extend Einstein's formula by

$$\mu_n = \mu_0 \left(1 - \phi_v\right)^{2.5}.$$

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 g u y e n C o m T a n g [8].

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 [8], for water – γ $Al_2O_3$ nanofluid

$$\mu_n = \mu_0 \left(306\phi_v^2 - 0.19\phi_v + 1\right)\mu_0.$$

These equations were used to perform the calculation of temperature distribution and transmission fields in the geometry studied.

## 3. Geometry and Boundary Conditions

Fig. 1 shows the geometric configuration of the studied model which consists of a coaxial heat exchanger with length $L$ = 64 cm; inner tube diameter $d$ = 10 mm and outer tube diameter $D$ = 20 mm. By inner tube will circulate a nanofluid as primary agent, and by the outer tube will circulate pure water as

secondary agent. The nanofluid used is composed of aluminium oxide $Al_2O_3$ particles dispersed in pure water in different concentrations (1%, 3% and 5%).

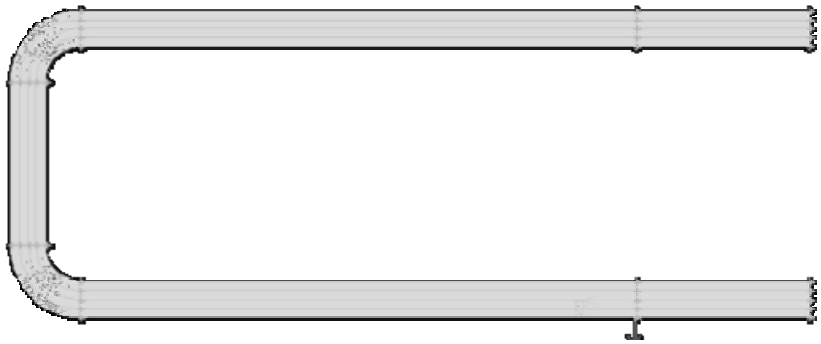

Fig. 1 – Geometry of coaxial heat exchanger.

The continuity, momentum and energy equations are non-linear partial differential equations, subjected to the following boundary conditions: at the tubes inlet, "velocity inlet" boundary condition was used. The magnitude of the inlet velocity varies for the inner tube between 0.12 m/s and 0.64 m/s, remaining constant at the value of 0.21 m/s for the outer tube. Temperatures used are 60°, 70°, 90°C for the primary agent and for the secondary agent is 30°C. Heat loss to the outside were considered null, imposing the heat flux to be null at the outer wall of heat exchanger. The interior wall temperature is considered equal to the average temperature value of interior fluid. Using this values for velocity, the flow is turbulent and we choose a corresponding model ($k-\varepsilon$) for solve the equations.

## 4. Results and Discussions

For mixing between the base fluid and the three types of nanofluids were performed numerical simulations to determine correlations between flows regime, characterized by Reynold's number, and convective coefficient values.

The convective coefficient value, $\alpha$, is calculated using Nusselt number for nanofluids, relation established following experimental determinations by X u a n and L i [9]

$$\mathrm{N}u_{nf} = 0.0023\ \mathfrak{R}e_{nf}^{0.8}\ \mathrm{P}r_{nf}^{0.4}.$$

The Reynold's number is defined by

$$\mathfrak{R}e_{nf} = \frac{u_m D}{\nu_{nf}}.$$

Prandtl number is

$$\mathrm{Pr}_{nf} = \frac{\nu_{nf}}{\alpha_{nf}}$$

and consequently

$$\alpha = \mathrm{N}u \frac{\lambda_{nf}}{d}.$$

The temperature and velocity profiles can be viewed post processing. In Fig. 2 is illustrated one example of the temperature profile visualization in a case study, depending on the boundary conditions imposed.

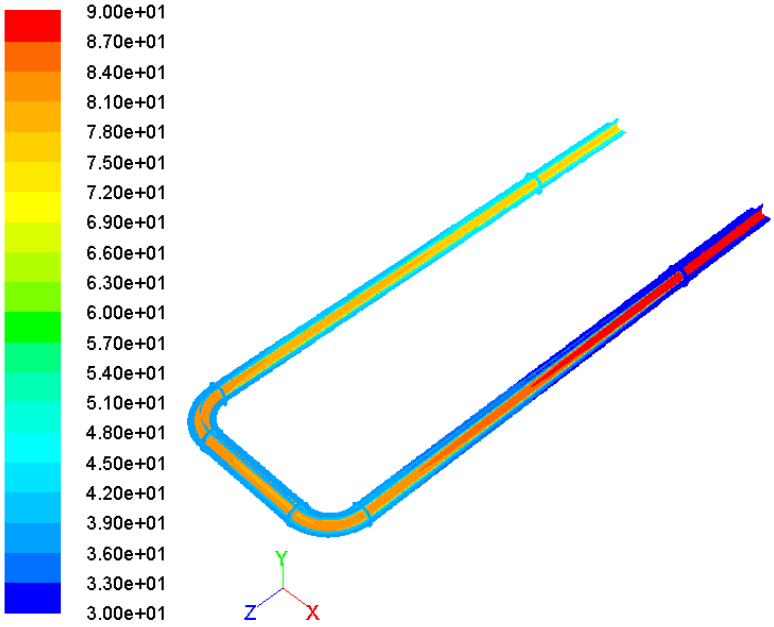


Fig. 2 – Temperature profile.

In what follows we analyse the variation of convective heat transfer coefficient in comparison with flow regime, temperature and nanofluids concentrations.

In Fig. 3 is represented the variation of convective heat transfer coefficient *vs.* the volume concentration of particles at imposed temperatures (60°, 70° and 90°C), at a constant Reynold's number (8,000).

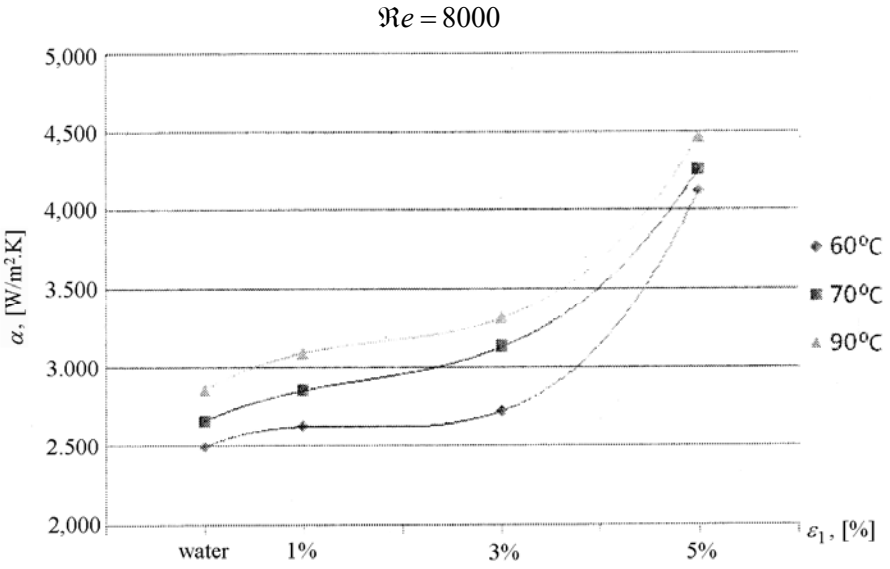


Fig. 3 – Variation of convective heat transfer coefficient *vs.* temperature at constant Reynold's number.

We can notice a significant increase of approximately 50% for convective heat transfer coefficient of nanofluid at the concentration of 5% compared with water at 90°C.

## 5. Conclusions

The obtained results clearly show that the addition of particles in a base fluid produces a great increase in the heat transfer. Intensification of heat transfer increases proportionally with increasing of volume concentration of these nanoparticles.

In the present model, the values of convective heat transfer coefficient and Nusselt number depend of flow regime and temperature values. When temperature is higher, the values of this coefficient increase.

**Notations**

$C$ – heat capacity, [J/kg.K];
$D$ – diameter, [m];
$k$ – thermal conductivity, [W/m.K];
N $u$ – Nusselt number;
P$e$ – Pectelt number;
P$r$ – Prandtl number;
$\Re e$ – Reynold's number;
$u$ – velocity, [m/s];
$\alpha$ – convective coefficient, [W/m$^2$.K];
$\rho$ – density, [kg/m$^3$];
$\phi_v$ – volumetric concentration, [%];
$\mu$ – dynamic viscosity, [kg/ms];
$v$ – kinematic viscosity, [m$^2$/s];

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$m$ – medium;
$nf$ – nanofluids;
0 – base fluid.

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## STUDIUL TRANSFERULUI TERMIC ÎNTR-UN SCHIMBĂTOR DE CĂLDURĂ COAXIAL UTILIZÂND NANOFLUIDE

(Rezumat)

Transferul termic al nanofluidelor într-un schimbător de căldură coaxial este studiat numeric folosind abordarea CFD (Computational Fluid Dynamics). Studiul efectuat indică o creştere a performanţelor termice a nanofluidelor cu 50% în comparaţie cu apa. Nanofluidul este compus din particule de oxid de aluminiu ($Al_2O_3$) dispersate în apă în diferite concentraţii (1, 3 şi 5%).