HEAT TRANSFER ENHANCEMENT BY USING TWO NANOPARTICLE BASE FLUIDS IN FORCED CONVECTION FLOWS

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ABSTRACT

In the present paper, forced laminar flow of Al_2O_3/water and Al_2O_3/Ethylene Glycol (EG) nanofluids inside the tube (heated partially and uniformly) were numerically investigated by using single phase method. The effects of nanoparticles concentrations (0 - 5%) and base fluids are investigated on the flow and the convective heat transfer behaviour.

The results obtained by the FLUENT software show that the enhancement in heat transfer is considerable when there are the nanoparticles in the base fluid. The wall temperature decreases with the increase in nanoparticles concentration, indicating that the heat transfer coefficient increases by increasing the concentration of nanoparticles in nanofluids. The Al_2O_3/Ethylene Glycol nanofluid has the highest Nusselt number than Al_2O_3/water nanofluid.

Mots Clés: *Numerical Simulation, Nanofluids, Forced Convection, Laminar Flow, Heat Transfer Augmentation.*

NOMENCLATURE

Symbols :

- Cp specific heat, $J \cdot kg^{-1} \cdot K^{-1}$
- D tube diameter, m
- h heat transfer coefficient, $W\ m^{-2}\ k^{-1}$
- k thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$
- L length of the tube, m
- Nu Nusselt number
- P Pression, pa
- q_w uniform heat flux, $W\ m^{-2}$
- T temperature, K
- V velocity, $m\ s^{-1}$
- Z axial direction

Greek symbols :

- μ viscosity, $kg\ m^{-1}\ s^{-1}$
- φ volume fraction
- ρ density, kgm^{-3}
- κ Boltzmann constant, $J\ k^{-1}$

Subscripts :

- av average
- b bulk
- bf base fluid
- nf nanofluid
- p nanoparticle
- w wall

1. INTRODUCTION

A nanofluid is a colloidal solution containing solid particles of small size (whose diameter is typically less than 100 nm), designated by the term "nanoparticles", suspended in a base liquid which is desired to modify or improve certain properties, particularly thermal. There are several kinds of nanoparticles: pure metals (aluminum, copper, titanium, gold, silver, iron ...), metal oxides (alumina, copper oxide, zinc oxide, ...), semiconductors, various ceramics (carbides, nitrides, sulphides ...), carbon nanotubes, fullerenes, diamond, polymers, etc. The nanoparticles are emitted mainly in suspension in water, oil or ethylene glycol.

Some experimental works treat the heat transfer by forced convection Al_2O_3/water nanofluid for various concentrations in circular tube maintained at constant temperature [1] and in microchannels [2]. The experimental results indicate that the coefficient of heat transfer of nanofluid increases with Peclet number, the Reynolds number and the concentration of nanoparticles. The increase in the coefficient of heat transfer is much higher than the results obtained by one-phase model. Other authors simulate the convective transfer in circular pipes with a single phase model [3] and / or two-phase model [4] for different Reynolds number, concentration and diameters of the nanoparticle. Their results confirm the previous results, and show that the coefficient of heat transfer augment with decreasing diameter of the nanoparticles. Some authors study the performance of nanofluids for cooling microchannels for different nannofluides [5] or different concentrations [6-7] their results confirm that nanofluids are preferment than the base liquid.

2. NUMERICAL SIMULATION

The geometry of the present problem is shown in Fig. 1. It consists of a circular tube with a diameter D of 0.01m and the length L of 1m, heated partially at the bottom with a constant heat flux while the top wall is considered adiabatic. In this problem laminar nanofluid flow that is a mixture of water and Al_2O_3 or Ethylene Glycol and Al_2O_3 nanoparticles with different concentrations enters the channel.

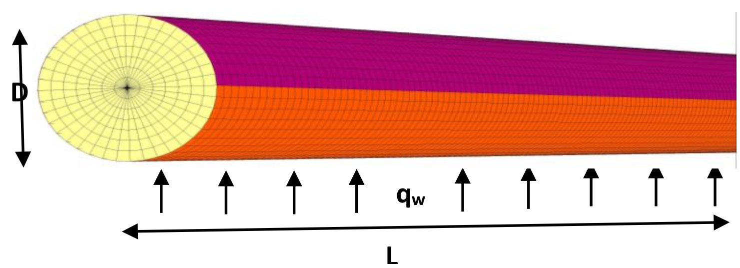

Figure 1. Geometry

The problem is modelled as laminar, steady state and the three-dimensional one phase model for the nanofluid. The governing mass, momentum and energy equations for the nanofluid can be written as follows:

Continuity equation

$$\nabla \cdot (\rho_{nf} V) = 0$$

Momentum equations

$$\nabla \cdot (\rho_{nf} V V) = -\nabla \cdot P + \nabla \cdot (\mu_{nf} \nabla V)$$

Energy equation

$$\nabla \cdot (\rho_{nf} C_p V T) = \nabla \cdot (k_{nf} \nabla T)$$

Both phases enter the channel at the inlet with the same uniform axial velocity that is specified according to the flow Reynolds number of 1000. Therefore, for both phases the no-slip and no temperature jump boundary condition at the walls are appropriate for the present study.

For thermal boundary conditions, it is assumed that the nanofluid enters the channel with 293 K and a constant heat flux ($5kW/m^2$) is applied from the bottom, while the top wall is considered adiabatic. For the channel outlet, the outflow boundary condition is considered for both phases

The thermophysical properties of the nanofluid formulated pertinent to the present study include the density, the specific heat, the thermal conductivity, and the dynamic viscosity, for which the following formulae in terms of the corresponding properties of the base fluid and the nanoparticle:

Density

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi \rho_p$$

Specific heat

$$C_{pnf} = \frac{(1-\phi)\rho_{bf} C_{pbf} + \phi \rho_p C_{pp}}{\rho_{nf}}$$

Thermal conductivity [8]

$$k_{nf} = \frac{k_p + 2k_{bf} - 2(k_{bf} - k_p)\phi}{k_p + 2k_{bf} + (k_{bf} - k_p)\phi}\, k_{bf} + 5\times10^4 \beta \phi \rho_{bf} C_{pbf} \sqrt{\frac{\kappa T}{\rho_p d_p}} f(T,\phi)$$

Where $f(T,\phi) = \left(2.8217\times10^{-2}\phi + 3.917\times10^{-3}\right)\left(\frac{T}{T_0}\right) + \left(-3.0669\times10^{-2}\phi - 3.91123\times10^{-3}\right)$

$\beta = 8.4407(100\varphi)^{-1.07304}$ for $\varphi \le 10\%$

Viscosity [9]

$$\mu_{nf} = A_1 e^{(A_2\phi)} \mu_{bf}$$

Where $A_1 = 0.983$ and $A_2 = 12.959$ for $\varphi \le 10\%$

In this work, the thermophysical properties of water, Ethylene Glycol and Al_2O_3 are listed in Table 1.

Properties	water	Ethylene Glycol	Al_2O_3
Density	**997**	**1114.4**	**3600**
Thermal Conductivity	**0.613**	**0.252**	**36**
Specific Heat	**4179**	**2415**	**765**
Viscosity	**0.000855**	**0.0157**	**/**

TABEL 1 . Thermophysical properties of nanoparticles and base fluids at T=300k

3. RESULTS

The simulations are carried out in the Fluent 6.3.26 environment.

The thermal conductivity of Al_2O_3/water and Al_2O_3/Ethylene Glycol (EG) as a function of nanoparticle volume concentration (ranging from 0-5%) are plotted in Figure 2. The thermal conductivity of the two nanofluids increases with the volume concentration of the Al_2O_3 nanoparticles. The enhancement increase is linearly proportional to the particle concentration. Al_2O_3/water has the highest thermal conductivity than that of Al_2O_3/ EG.

Figures 3-5 show the influence of the particle volume concentration ϕ on the wall temperature profile at the different tube sections. From fig 3 we can observe that the temperature of pure water is the highest as compared with all concentrations of Al_2O_3 /water nanofluids studied in this work. Also, it can be seen that temperature decreases with the augmentation of volume concentration of Al_2O_3 / water nanofluid.

Figure 4 shows the profile of temperature for Ethylene Glycol and Al_2O_3/EG nanofluid with different volume concentration. The increasing the volume concentration of nanoparticles can enhance the cooling performance.

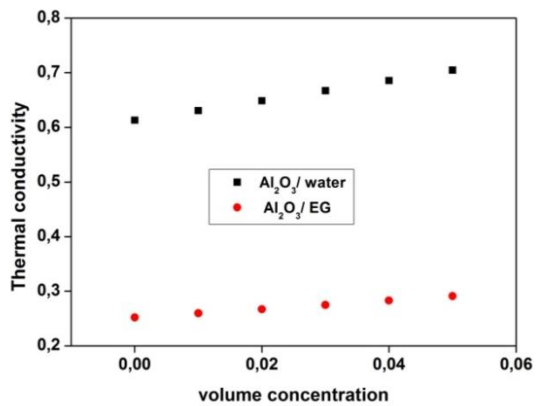

FIGURE 2 .Thermal conductivity for nanofluids in different volume concentration

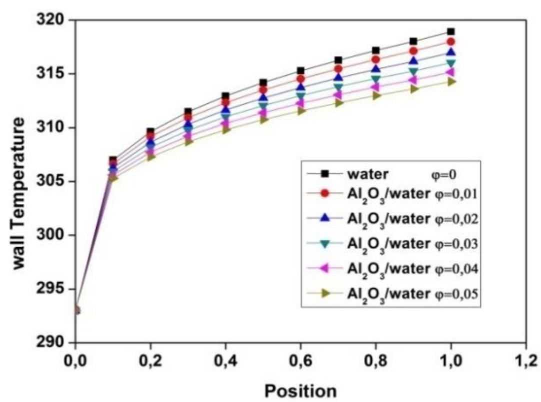

FIGURE 3. Wall emperature profile for water and different concentration of Al_2O_3 / water nanofluid

From fig 5 it is observed that Al_2O_3/water and Al_2O_3/EG nanofluid have the lowest value of temperature while water has the highest value of temperature. As it can be seen, in both nanofluides, considerable increases in temperature are obtained when we use water as base fluid. For example, the temperature of water and Al_2O_3/water for 1% volume concentration is very highest than that of Al_2O_3/EG for a 1% and 5% volume concentration especially at the tube exit.

The average heat transfer coefficient ($h_{av} = \frac{1}{L}\int_0^L h(z)\,dz$) of Al_2O_3/ water and Al_2O_3/EG nanofluids and average Nusselt number ($Nu_{av} = \frac{h_{av} \cdot D}{k}$) are shown in Figures. 6 and 7 respectively.

Where *h(z)* is local heat transfer coefficient computed as: $h(z) = \frac{q}{T(z)_w - T(z)_b}$

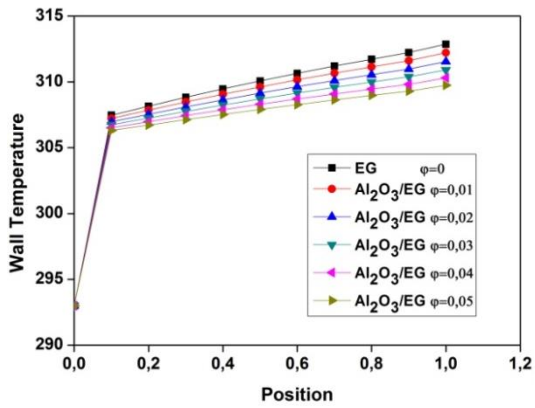

FIGURE 4 .Wall temperature profile for EG and different concentration of Al_2O_3 / EG nanofluid

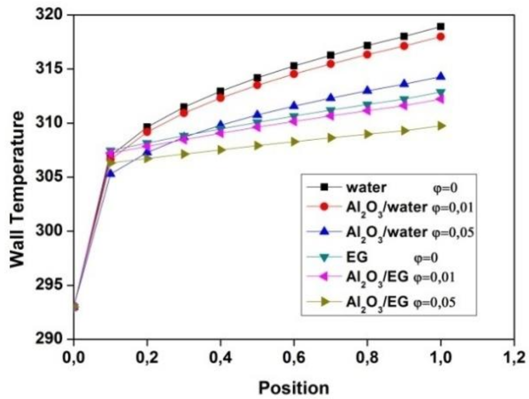

Figure 5 .Wall temperature profile for water, Al_2O_3 / water, EG and Al_2O_3 / EG nanofluids.

figure 6 illustrates the increase in the heat transfer with the increase in nanoparticle volume concentration. This is due to higher convective effects and higher nanoparticle participation in the nanofluid thermal conductivity enhancement, respectively. We can see that the average heat transfer coefficient of Al_2O_3/water is great than that of Al_2O_3/EG nanofluids.

figure 7 shows that there is a big difference between the average Nusselt number of Al_2O_3/water and that of Al_2O_3/EG nanofluids because the thermal conductivity of Al_2O_3/water is highest than that of Al_2O_3/EG.

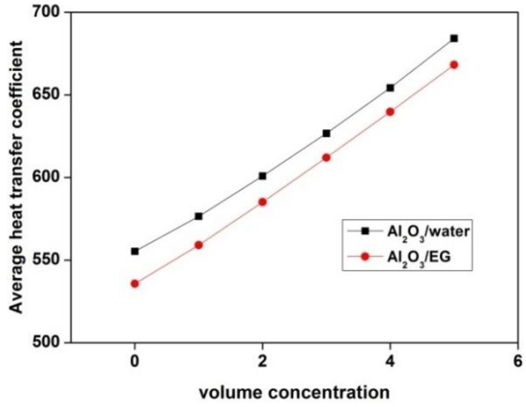

Figure 6 Average heat transfer coefficient for Al_2O_3/ water and Al_2O_3/EG nanofluids in different volume concentration

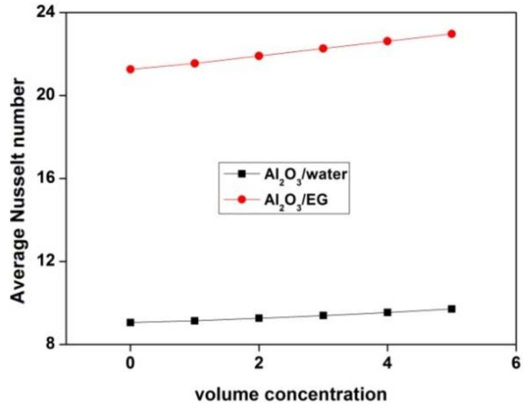

Figure 7 .Average Nusselt number for Al_2O_3/ water and Al_2O_3/EG nanofluids in different volume concentration

4. CONCLUSIONS

Numerical simulations are performed to investigate the laminar flow and heat transfer characteristics of Al_2O_3/water and Al_2O_3/EG nanofluids inside a tube heated partially. The single -phase method is used to simulate the nanofluid flow. The results show that the Al_2O_3/water and Al_2O_3/EG nanofluid have the lowest temperature and the highest heat transfer coefficient. Whereas, pure water has the highest temperature and the lowest heat transfer coefficient. The Al_2O_3/ water has the best performance in terms of heat transfer coefficient than Al2O3/ EG nanofluid. but the Nusselt number of Al_2O_3/EG is great than that of Al_2O_3/water nanofluids. The heat transfer coefficirnt and Nusselt number increased as the nanoparticle volume concentration increased.

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