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CFD Simulation of Forced Convection Heat Transfer Enhancement in Pipe Using Al2O3/Water Nanofluid

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ABSTRACT

The advanced concepts of nano fluids offer an improvement in heat transfer compared to conventional heat transfer fluids. In recent years, researchers have been more attentive to the importance of higher thermal properties of nanofluids, especially in thermal conductivity and heat transfer. In this research, a numerical computational fluid dynamics (CFD) simulation is performed for forced convection heat transfer of Al2O3 nanofluids in a circular pipe with constant heat flow is carried out. The convective heat-transfer coefficient, Nusselt number, and friction factor of a nanofluid are studied as a function of Reynolds number and particle volume fraction. Volume fractions of 0.5, 1.0, and 2.0 percent of Al2O3 nanoparticles are studied, with range of Reynolds number of 6000 to 12000. The numerical results show that nanofluids have better convective heat performance than basic fluids, and the heat transfer improvement increases with the Reynolds number of the particles and volume concentration.

Keywords:
Heat transfer; Forced convection; Nano-fluids; Ansys Fluent

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1. Introduction

Many researchers have demonstrated the characteristics of heat transfer in thermal pipes with nanofluids [1-3]. Choi and Eastman [4] first proposed the concept of nanofluid. That is, adding nano-scale metals and metal oxide particles to liquids in a specific way and proportion form a new type of working fluid for heat transfer and cooling. Keblinski *et al.* [5] carried out an interesting review of the properties and future challenges of nanofluids. Aluminum oxide nanoparticles (Al_2O_3) are widely used in experiments and numerical studies [6,7]. Wen and Ding [6] developed a series of experiments using Al_2O_3-water nanofluids in a circular tube. Anoop et al. [7] conducted experiments using Al_2O_3-water to calculate the heat transfer coefficient considering the influence of particle size. Experimental results showed an increase in the thermal transfer coefficient of 25% at particle sizes of 45nm. In this study, a numerical heat transfer enhancement of nanofluids (water-Al_2O_3) in a two-dimensional horizontal pipe has been investigated. Numerical analysis is performed with the finite-volume method using FLUENT software.

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2. Mathematical Formulation
2.1 Geometry Configuration

A schematic view of the physical problem and boundary conditions is shown in Fig. 1. The nano fluid enters a pipe of radius 0.06 m at a constant velocity of 0.001 m/s. The fluid has a density of 1000 kg/m^3, a thermal conductivity of 0.6 W/m-K, a specific heat of 4180 J/kg-K, and a viscosity of 1.002×10^{-5} kg/m-s. The first 5.76 m of the pipe is isothermal, held at 300 K. The remaining 2.88 m of the pipe have a constant heat flux of 10Kw/m^2 added at the wall.

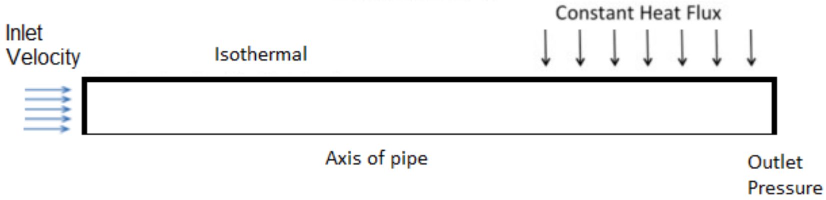

Fig. 1. Problem Specification

2.2 Governing Equations and Boundary Conditions:

Because nanofluids are composed of very small particles, nanoparticles and base fluid are considered to be in in thermal equilibrium and flow at the same velocity. In the energy equation, the terms compression work and viscosity dissipation were considered negligible. According to these assumptions, the general rule equation is as follows [8-11]:

Continuity equation:

$$\nabla.(\rho_{nf}V) = 0 \tag{1}$$

Momentum equation:

$$\nabla.(\rho_{nf}VV) = -\nabla P + \nabla.\tau \tag{2}$$

Energy equation:

$$\nabla.(\rho_{nf}VC_{p,nf}) = -\nabla.(k_{nf}\nabla T - C_{p.nf}\rho_{nf}\overline{\mathrm{v}t}) \tag{3}$$

2.3 Nanofluid Thermo-Physical Properties

The thermophysical properties of nanofluids are mainly the function of particle volume and temperature. Since there are no experimental data, the density and specific heat of nanofluids are defined as the following fractional functions [2,3,12]:

Nanoparticle volume fraction in nanofluid:

$$\phi = \frac{V_{np}}{V_{bf}+V_{np}} \tag{4}$$

Density of nanofluid:

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_{np} \tag{5}$$

Specific heat of nanofluid:

$$C_{p,nf} = \frac{(1-\emptyset)\rho_{bf}C_{p,bf}+\emptyset\rho_{np}C_{p,np}}{\rho_{nf}} \quad (6)$$

Thermal conductivity of nanofluid:

$$\frac{k_{nf}}{k_{bf}} = \frac{(k_{np}+2k_{bf})-2\emptyset(k_{bf}-k_{np})}{(k_{np}+2k_{bf})+\emptyset(k_{bf}-k_{np})} \quad (7)$$

Viscosity of nanofluid:

$$\mu_{nf} = \mu_{bf}\frac{1}{(1-\emptyset)^{2.5}} \quad (8)$$

Based on the equations above, the volume fraction of nanoparticle is $\emptyset$, V_{bf} is base fluid volume, V_{np} as the volume of nanoparticle. Other than that, ρ_{np} (kg/m^3) is the nanoparticle's density while ρ_{bf} (kg/m^3) is the base fluid's density. The specific heat is $C_{p,nf}$(J/kg.K) for nanofluid while $C_{p,bf}$(J/kg.K) is for base fluid, k_{nf} (W/m.K) represents the nanofluid thermal conductivity while k_{bf} (W/m.K) is the base fluid's thermal conductivity, k_{np}(W/m.K) is nanoparticle's thermal conductivity. Lastly, μ_{nf}(Pa.s) and μ_{bf}(Pa.s) are viscosity of nanofluid and base fluid respectively.

Table **1**

Thermophysical properties of Al_2O_3 nanofluid
shows the water and Al_2O_3 characteristics, and the proposed nanoparticles, Al_2O_3. The thermophysical characteristics formulas are shown in the section below.

Table 1
Thermophysical properties of Al_2O_3 nanofluid

Property	Water	Al_2O_3
Density (kg/m^3)	998.2	3970
Specific heat (J/kg.K)	4182	765
Thermal conductivity (W/m.K)	0.6	40
Viscosity (Pa.s)	0.001	-

3. Results

Figure 1 shows the temperature contours along the pipe. The temperature is constant along the isothermal part of the pipe and is varying along the heat flux region. The temperature is high at the pipe wall and is gradually decreasing towards the centreline.

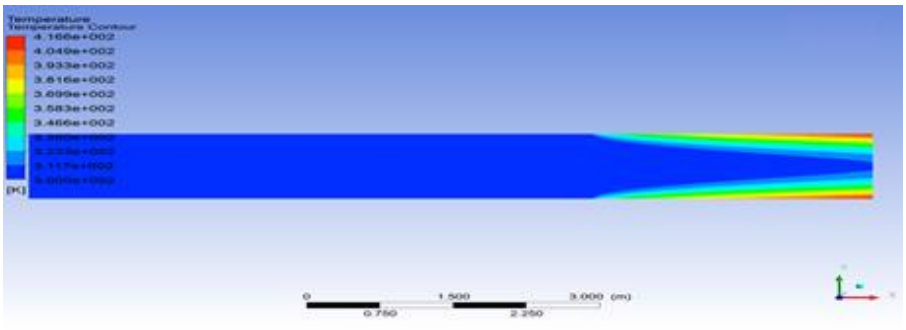

Fig. 2. Temperature contour along the pipe

Figure 3 shows that heat transfer coefficient grows linearly with Reynolds number. The heat transfer coefficient of the Al_2O_3 nanofluid is superior to that of water due to the improved thermophysical characteristics of the nanofluids due to the dispersion in water. The addition of solid nanoparticles to water has improved thermal conductivity resulting in an increase in the heat transfer coefficient.

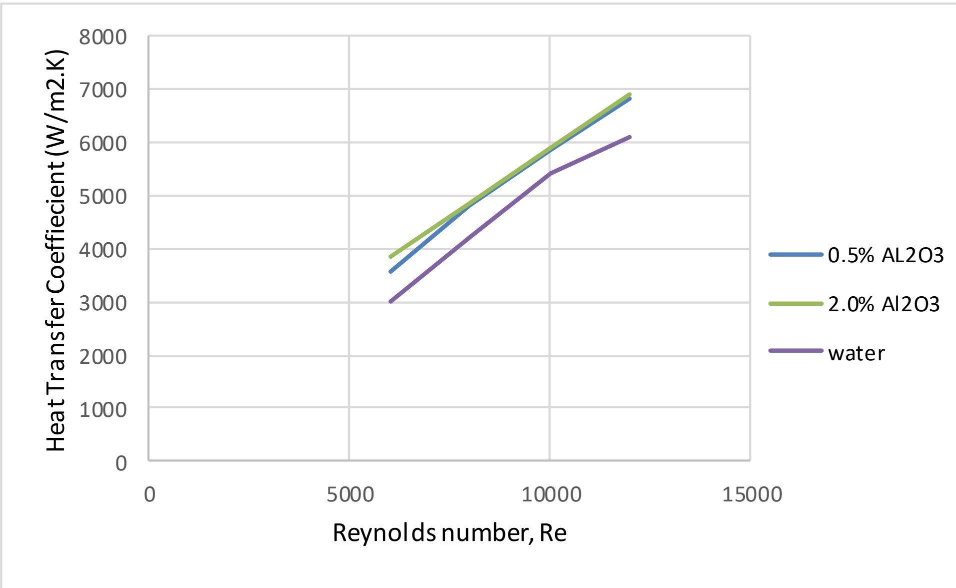

Fig. 3. Effect of nanoparticle concentration on convective heat transfer coefficient

Based on the results in Figure 4, Nusselt number increases as the Reynolds number increases. This is also influenced by the volume fraction increase where Nusselt number is higher when the volume fraction of the Al_2O_3 nanofluid increases.

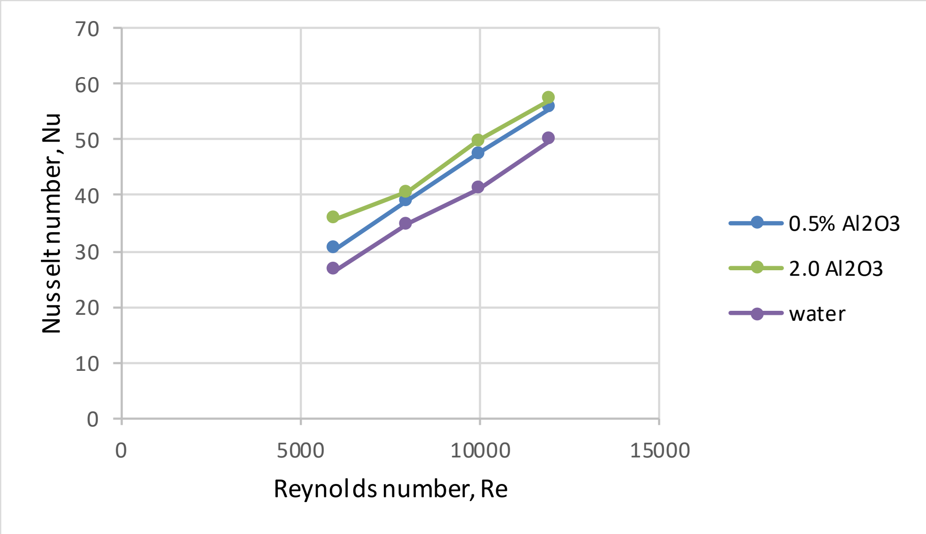

Fig. 4. Effect of nanoparticle concentration on Nusselt number

4. Conclusions

A numerical CFD simulation for a forced convection heat transfer in a horizontal pipe is carried out using the commercial CFD ANSYS Fluent code. The simulation is carried out for pure water and water with nanoparticles as a cooling fluid. Ansys fluent software was used to study the effect of suspension of nano particles of Al_2O_3 into water as a base fluid and to determine to what extent 2D modelling is sufficient to display the behaviour of thermohydraulic characteristics of the convective heat transfer flow through pipes. According to the numerical results, adding nanoparticles to the fluid improved heat transfer and the Nusselt number in the flow.

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