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Heat Transfer Enhancement in Pipe Using Al_2O_3/Water Nanofluid

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ABSTRACT

Convection heat transfer is widely used in many industrial heat and cooling systems. The heat convection can be enhanced passively by adding metal nanoparticles in the water that have been adequately consumed. Small solid metals or nanoparticles of metal oxides floating in the base liquid increase the efficiency of thermal transmission in the system. Commercial CFD code FLUENT is used to simulate water-based nanofluids and is considered to be a single-phase fluid. The effects of various parameters such as Nusselt number and friction factor are studied as a function of Reynolds number and particle volume fraction. The volume fraction of 0.5, 1.0, and 2.0 percent of the Al2O3 nanoparticles was investigated, with Reynolds numbers between 6000 and 12,000. The numerical results show that nanofluids have a higher efficiency in convection heat than basic fluid and an improved thermal transfer efficiency with Reynolds numbers and volume concentrations.

1. Introduction

Many researchers have demonstrated the properties of thermal transmission in nanofluid thermal pipes [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 [5,6].

In order to estimate the thermal conductivity of nanofluids, theoretical and experimental research was carried out. Some experimental studies have shown that the thermal conductivity of nanofluids measured is larger than the theoretical predictions of classical theory [7]. Other experimental studies [8,9] have shown that thermal conductivity does not exhibit abnormal improvement, and the results are well consistent for low volume [7,10]. Efforts are being made to formulate effective theoretical models for predicting effective thermal conductivity, but this topic remains seriously incomplete. Keblinski *et al.,* [11] carried out an interesting review of the properties and future challenges of nanofluids. Aluminum oxide nanoparticles (Al_2O_3) are widely used in

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experiments and numerical studies [12,13]. Wen and Ding [12] developed a series of experiments using Al_2O_3-water nanofluids in a circular tube. Anoop *et al.,* [13] 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.

2. Mathematical Formulation

2.1 Geometry Configuration

Figure 1 shows a schematic of physical problems and boundary conditions. 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.

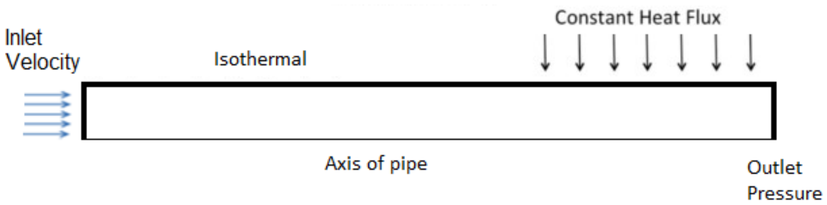

Fig. 1. Problem Specification

2.2 Governing Equations and Boundary Conditions

Nanofluids are composed of very small particles, so nanoparticles and base liquids are considered to be thermally balanced and flow at the same speed. In energy equations, compression work and viscosity dissipation are considered to be insignificant. Based on these hypotheses, the general equation of the rule is as follows. [14-17]:

Continuity equation:

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

Momentum equation:

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

Energy equation:

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

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 [2,3,18,19]:

Nanoparticle volume fraction in nanofluid:

$$ø = \frac{V_{np}}{V_{bf}+V_{np}} \quad (4)$$

Density of nanofluid:

$$\rho_{nf} = (1-ø)\rho_{bf} + ø\rho_{np} \quad (5)$$

Specific heat of nanofluid:

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

Thermal conductivity of nanofluid:

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

Viscosity of nanofluid:

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

Based on the equations above, the volume fraction of nanoparticle is $ø$, 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 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 2 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.

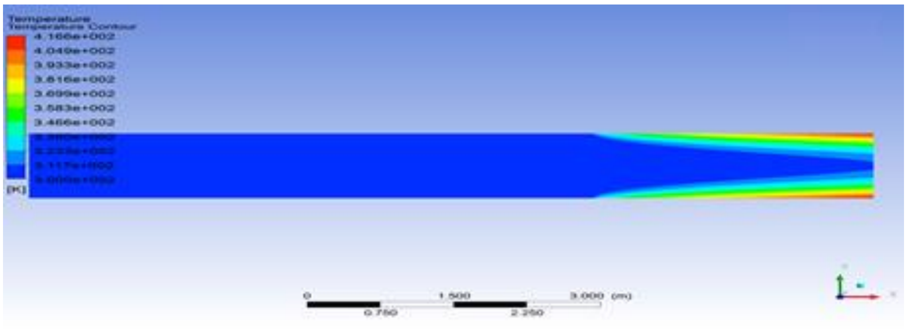

Fig. 2. Temperature Contour along the pipe

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.

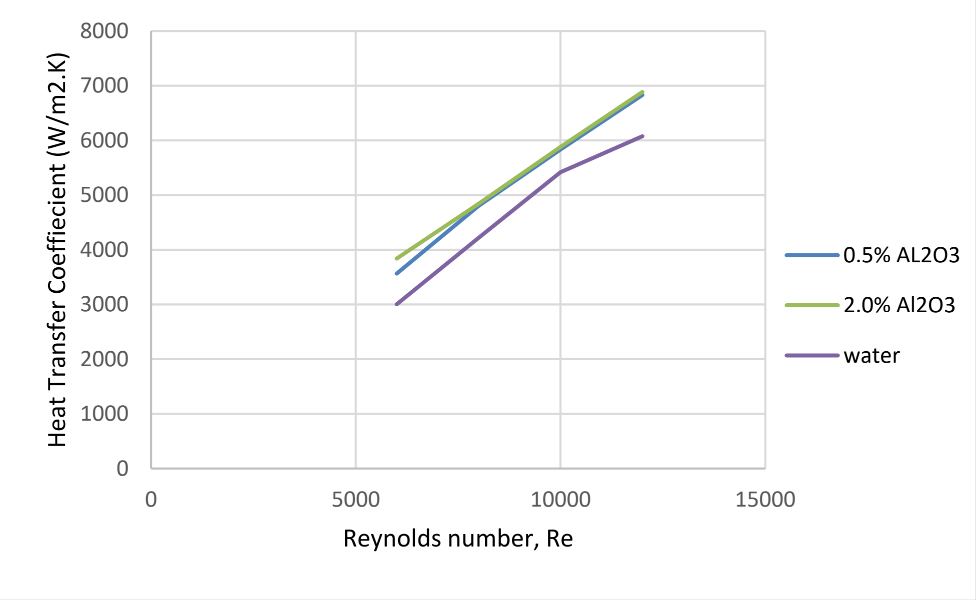

Fig. 3. Effect of nanoparticle concentration on convective heat transfer coefficient

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.

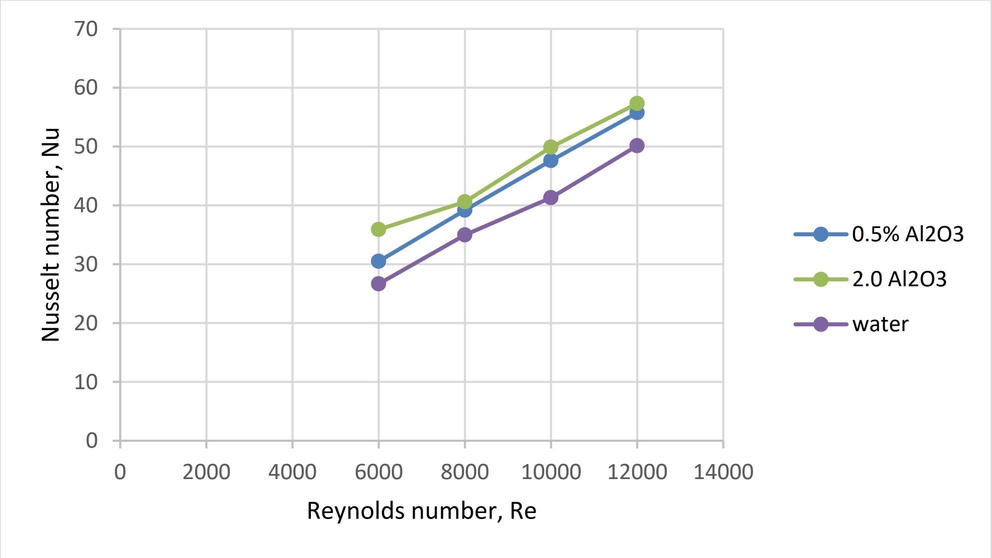

Fig. 4. Effect of nanoparticle concentration on Nusselt number

Figure 5 shows the impact of volume fractions and Reynolds numbers on water friction factors and Al2O3 nanofluids.

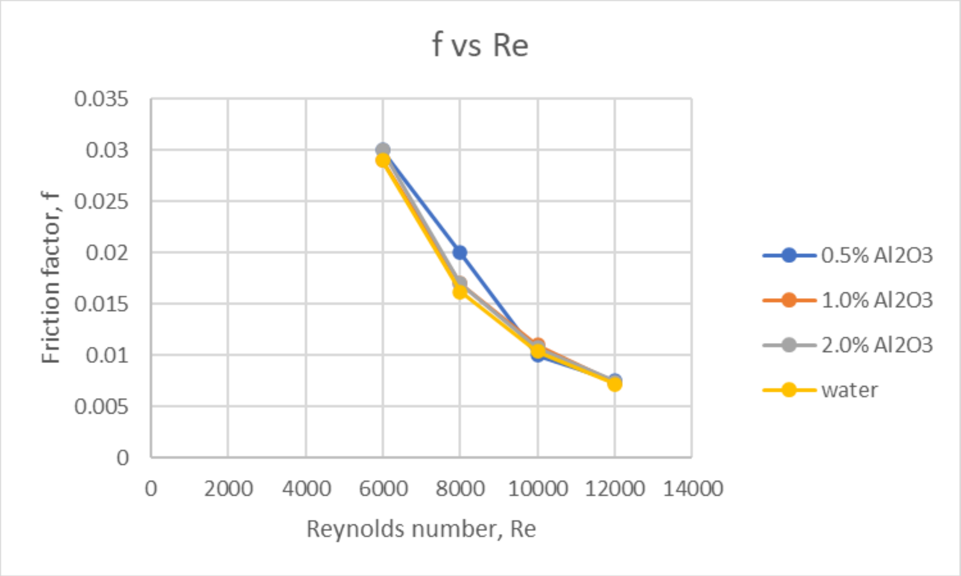

Fig. 5. Comparison of friction factor between present study and water

The friction factor of Al_2O_3 nanofluids is higher than that of water, and as the volume increases, the friction factor increases. This is due to the fact that nanofluids have a viscosity higher than water and increase in volume fraction. Al_2O_3 nanofluid density is higher than water density, so nanofluid velocity is lower. Among Al_2O_3 and water, the 2.0% nanofluid had the greatest friction factor. As Reynolds increased from 6000 to 20,000, nanofluid friction factors increased by 0.1%.

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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