

Water Based Nanofluids: A Computational Study on Temperature Distribution in a Pipe Flow

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Abstract

Fluid containing nanometer-sized particles (*i.e.* nanoparticles) is known as nanofluid. Three different nanofluids flowing in a pipe with heat source at the inlet and sink in the walls are studied. The base fluid is water. 20 nm size nanoparticle Al_2O_3 is mixed with base fluid with volume concentrations of 0.1%, 0.2% and 0.5%. Simulation is done using ANSYS Workbench 17.1. The result shows correlation between concentration of nanoparticle and temperature gradient at the outlet of the pipe.

Keywords

Nanofluid, Nanoparticle, Al_2O_3 , CFD, ANSYS

1. Introduction

Nanofluids (nanoparticles fluid suspensions) [1] is the term introduced by Choi *et al.* [2]. Nanofluids based heat transfer fluids have better thermal properties than the host fluids. Solid nanoparticles such as metal or metal-oxide (ranging from 1 to 100 nm size) are diffused in traditional liquids e.g. water, ethylene glycol and engine oils etc. to prepare nanofluids. To gain highest possible thermal properties by dispersing nanoparticles (preferably less than 1 nm) uniformly at small possible volume concentration (preferably less than 1%) as well as maintaining a stable suspension is the main concern of nanofluids.

Transfer of heat energy has become a major task in industrial processes [3]. Heat must be added, removed or exchanged between process streams throughout various industrial processes. Study of nanofluid shows that it can be used as a high performance heat transfer medium. The diffused nanoparticles allow

more heat transfer by increasing thermal conductivity of the nanofluids along with conduction and convection heat transfer coefficient. Behind the enhancement of thermal properties of nanofluids the main reasons are increment of relative surface area, effective thermal conductivity, mixing fluctuation and turbulence of the fluid and among others [3].

In this study, three different nanofluids were studied inside a pipe with flow and heat transfer.

2. Problem Statement

A situation is considered where fluid is flowing through a pipe. The pipe is connected with both source and sink. Then three different types of nanofluids are investigated in respect to their temperature distribution at the outlet. The base fluid is water, which has been investigated at first to compare the nanofluids results. Nanoparticle aluminum oxide is mixed with base fluid at volume concentrations (0.1%, 0.2%, and 0.5%) to create three different nanofluids. These liquid-solid nanofluids are treated as single fluid in Fluent using their representative thermal and physical properties. Experimental values [1] of the nanofluids have been used for this purpose (Table 1).

2.1. Physical Model

At the beginning a situation following the Example 8-3 [4] is reproduced using Fluent. Schematic diagram of the system is shown in Figure 1.

At the inlet fluid is flowing with a constant temperature. The pipe wall is always at 273.15 k temperature as according to Example 8-3 [4], the pipe goes through an ice lake with temperature 273.15 k.

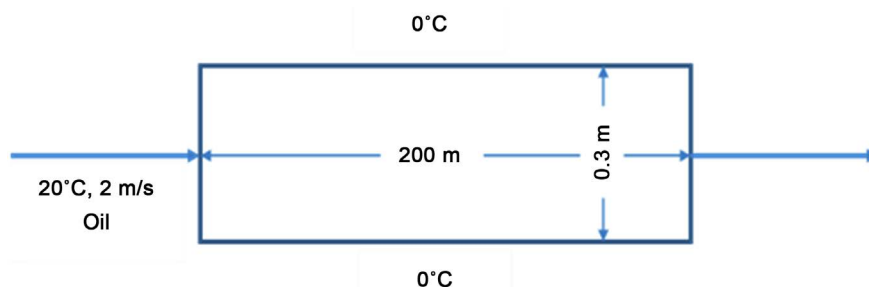


Figure 1. Schematic diagram of the system.

Table 1. Properties of nanofluids.

Property	Volume Concentration of Al ₂ O ₃		
	0.1% Al ₂ O ₃	0.2% Al ₂ O ₃	0.5% Al ₂ O ₃
Density ρ (kg/m ³)	1038	1042	1060
Specific heat C_p (j/kg-k)	3200	2600	500
Thermal conductivity K (W/m-k)	0.6	0.615	0.65
Viscosity μ (kg/m-s)	0.0007	0.00068	0.0006

Continuity (Equation (1)), momentum (Equation (2)) and energy equations (Equation (3)) are solved to get result.

$$(\partial\rho/\partial t) + \nabla \cdot (\rho\mathbf{V}) = 0 \quad (1)$$

$$\rho(\partial\mathbf{V}/\partial t) + \rho(\mathbf{V} \cdot \nabla)\mathbf{V} = -\nabla\rho + \rho\mathbf{g} + \nabla \cdot \boldsymbol{\tau}_{ij} \quad (2)$$

$$(\partial/\partial t) \int e^* \rho dV + \int (\hat{u} + P/\rho + V^2/2 + gz) \rho \mathbf{V} \cdot \hat{n} dA = \dot{Q}_{net\ in} + \dot{W}_{net\ in} \quad (3)$$

After reproducing, the result of Example 8-3, the properties of the fluid are changed to mimic nanofluids. Temperature gradient at the outlet of the pipe is studied and trend is identified with the volume concentrations of nano particles in the base fluid.

2.2. Numerical Procedure

Considered geometry is two-dimensional planar. For simplicity, 3D geometry is avoided, which is a consideration for future cases. 2500×15 mesh grid is used for this simulation. Simulation parameters are provided in **Table 2**.

The flow is calculated laminar for every case studied in this paper. Reynolds number is less than critical Reynolds number 2300 in all cases considered.

2.3. Grid Size Convergence

In order to avoid inaccurate result due to poor mesh density, different element numbers were used to analyze the mesh sensitivity. Three different element numbers (*i.e.*, 1250, 3750, 37,500) have been used to compare temperature at the outlet of the pipe. It is found the element number converges after 3750 (**Figure 2**).

3. Results

Hagen-Poiseuille equation (Equation (4)) is used to compare the pressure drop along the pipe.

$$\Delta p = \frac{8\mu L Q}{\pi R^4} \quad (4)$$

Table 2. Simulation parameters.

Solver-Type	Pressure based
Solver-Time	Steady
Energy Model	On
Viscous Model	Laminar
Wall	Stationary
	Constant temperature
	Scheme: SIMPLE
Solution method	Energy: 2 nd order upwind
	Momentum: 2 nd order upwind

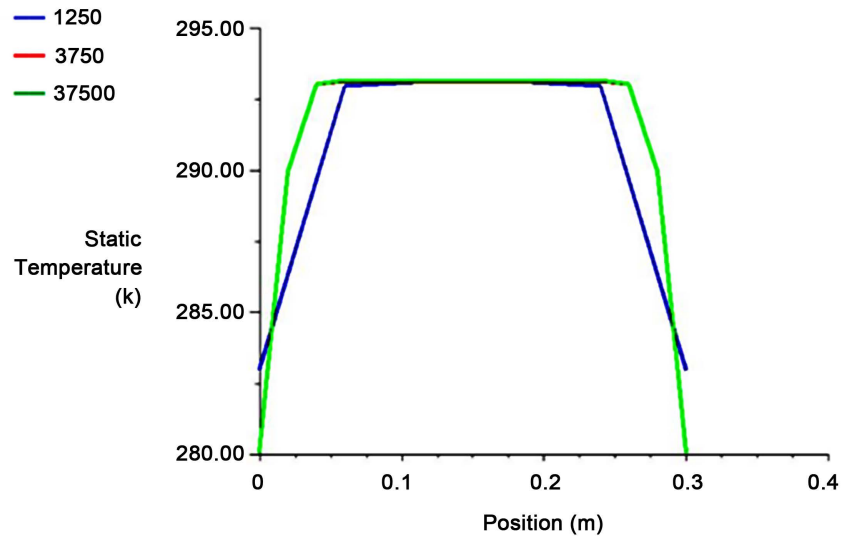


Figure 2. Mesh element convergence.

Here, μ (for water) = 0.001003 kg/m·s, L (pipe length) = 200 m, v (fluid velocity) = 2 m/s, R (pipe radius) = 0.15 m, Q (=area of pipe cross section $\times v$) represents discharge rate. The pressure drop along the pipe (Δp) is found 142.65 Pa. The simulated result from Fluent is in close proximity of the calculated value (**Figure 3**).

Noticeably pressure fluctuates at the end of the pipe length. This happens due to the local back flow.

Equation (5) is used to calculate temperature at the end of pipe.

$$T_e = T_s - (T_s - T_i) \exp\left[-hA_s / \dot{m}C_p\right] \quad (5)$$

$$h = 10.45 - v + 10v^{1/2} \quad (6)$$

Here, T_e , T_s and T_i represent temperatures of outlet, surface and inlet of the pipe respectively; h —convective heat transfer coefficient of water, A_s —surface area of pipe, \dot{m} —mass flow rate.

The calculated value of the temperature at the end of pipe is 302.93 K (**Figure 4**).

Flow is fully developed at some downstream distance of inlet (**Figure 5**). This distance is much higher than lower viscosity and dense fluid e.g. air (**Figure 6**).

4. Analysis on Nanofluids

At this point, the properties of the fluid are changed to mimic nanofluids. Experimental thermophysical properties of nanofluids were taken from [1]. Total four fluids were compared in terms of temperature gradient at the outlet of pipe (**Figure 7**). These are the base fluids water and three nanofluids, which are composition of water and three different volume fractions (*i.e.* 0.1%, 0.2%, and 0.5%) of aluminum oxide nano particles. Noticeably from pure water to with increasing volume fraction of nanoparticle, we see the wall temperature drops to

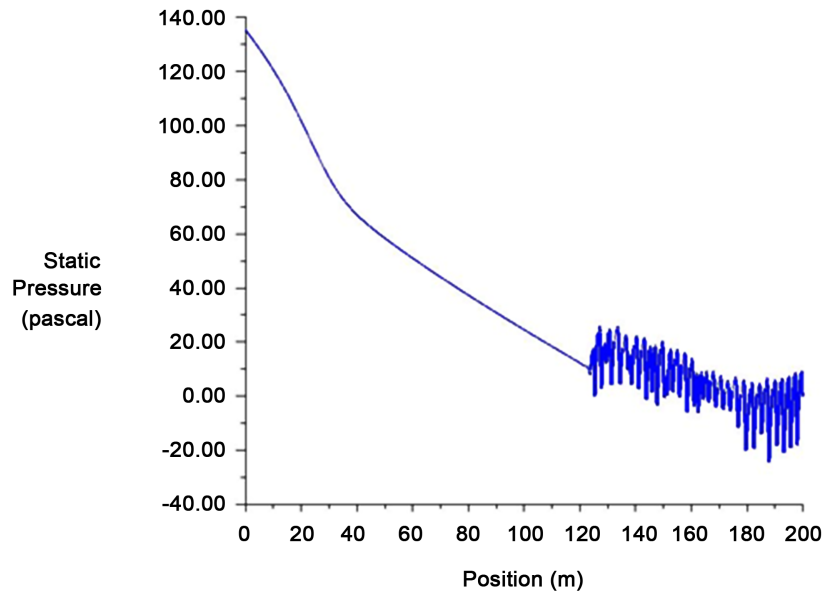


Figure 3. Pressure distribution along pipe axis (water).

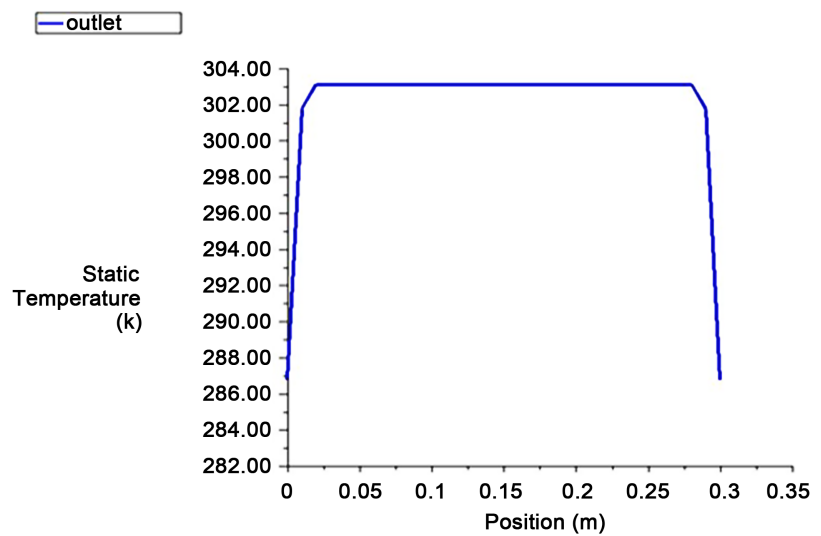


Figure 4. Temperature distribution at outlet (water).

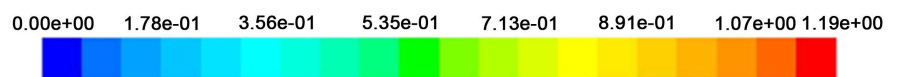


Figure 5. Velocity contours (Water).

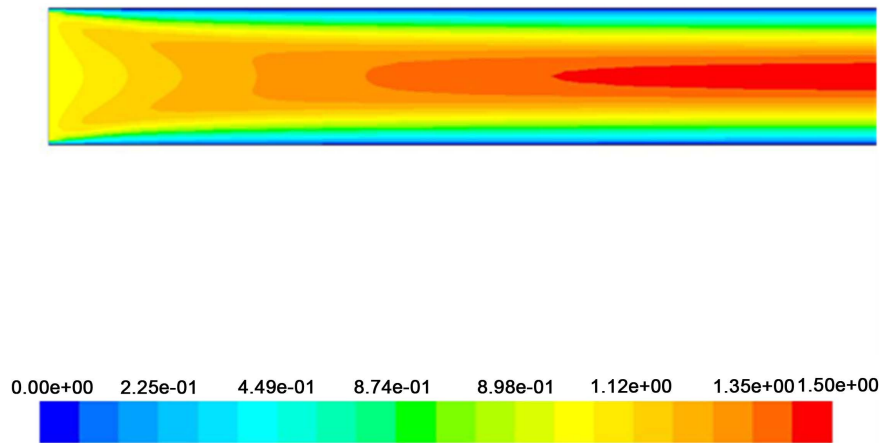


Figure 6. Velocity contours (air).

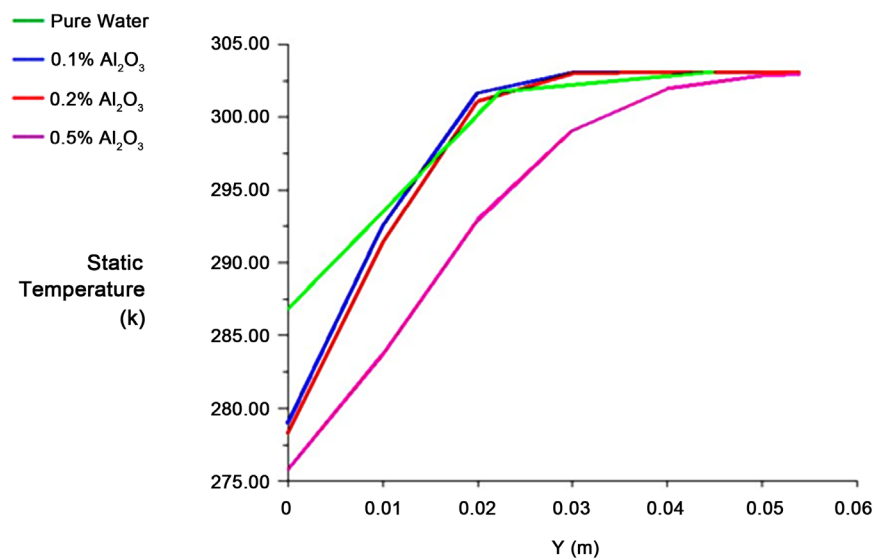


Figure 7. Temperature distribution at the outlet.

smaller values. This shows that with a very small amount of addition of nanoparticles, these nanofluids' thermal properties can be varied to a large extent.

5. Conclusion

After investigating three nanofluids in a pipe flow in terms of their temperature distribution at the outlet, it is found that with increasing volume fraction of aluminum oxide, temperature at the outlet wall decreases. The initial conclusion suggests that nanofluids have a potential to work as an industrial thermal fluid with superior thermophysical properties.

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