International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Effect of Nanofluid on Friction Factor of Pipe and Pipe Fittings: Part I - Effect of Aluminum Oxide Nanofluid

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Accepted 30 Nov 2014, Available online 01 Dec 2014, **Vol.4, No.6 (Dec 2014)**

Abstract

A nanofluid is a mixture of nano sized particles and a base fluid. Typical nanoparticles are made of metals, oxides or carbides, while base fluids may be water, ethylene glycol or oil. Generally, nanofluids are used to enhance heat transfer rate. The heat transfer enhancement using nanofluid mainly depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid. Due to utilization of nanofluid, resistance to flow of fluid increases which increases the friction factor and reduces the flow rate. In the present paper, an experimental investigation is carried out to determine the effect of various concentration of Al_2O_3 nano-dispersion mixed in water as base fluid. The volume concentrations of Al_2O_3 nanofluid prepared are 0.001 %, 0.002 %, 0.003 % and 0.004 %. The conclusion derived for the study is that friction factor and loss coefficient of different pipes and pipe fittings increase with increase in volume concentration of Al_2O_3 nano-dispersion compared to water.

Keywords: *Nanofluid, Friction Factor, Pipe, Pipe Fittings, Aluminum Oxide.*

1. Introduction

A nanofluid is a mixture of nano sized particles and a base fluid. Typical nanoparticles are made of metals, oxides or carbides, while base fluids may be water, ethylene glycol or oil. The nanofluid exhibits different thermo physical properties than the base fluid. Generally thermal conductivity of nanofluids is higher than the base fluid which increases the heat transfer rate. The heat transfer enhancement using nanofluid mainly depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid.

When the fluid is flowing through the pipe, some head is lost to overcome the hydraulic resistance due to friction of the fluid with the inner surface of the pipe wall, viscosity of fluid and turbulence of the fluid flow. There are two types of head loss during fluid flow viz. (1) Major Head Loss and (2) Minor Head Loss. Major head loss is due to friction during the fluid flow while minor head loss is due to disturbance in fluid flow pattern during the flow of fluid through sudden enlargement, sudden concentration, bend, elbow etc.

Many researchers have studied numerically and experimentally the phenomenon of effect of nanofluid on friction factor. The studies reported recently in literatures have been referred and presented here.

Numerically three-dimensional turbulent flow and heat transfer of two different nanofluids for nanoparticles volumetric concentrations up to 6%, containing aluminum oxide (Al_2O_3) and copper oxide (CuO) nanoparticles, dispersed in ethylene glycol and water mixture (EG/W) in the flat tubes of an automotive radiator have been studied to evaluate their performance. For the same Reynolds number, nanofluids show an increase of friction factor and heat transfer coefficient with an increase in the particle volume concentration (Vajjha, *et. al.*, 2015). Experimental investigation on heat transfer coefficient and friction factor of TiO_2 and SiO_2 water based nanofluids with an average particle size of 50 nm and 22 nm respectively and volume concentrations up to 3.0 % flowing in a circular tube under turbulent flow under constant heat flux boundary condition. The conclusion derived is that the pressure drop is directly proportional to the density of the nanoparticle (Azmi, *et. al.* 2014). Experimental investigatigation on the effect of nanoparticles and helical corrugation on turbulent heat transfer and dimensionless friction factor have been carried out. Research has shown that the heat transfer and friction factor increase by increasing nanofluid concentrations in plain and helical corrugated tube while its effect are more significant in helical corrugated tubes. (Darji, *et. al.* 2014)

Experimental studies are carried out to investigate heat transfer and friction factor characteristics of γ-Al_2O_3/water nanofluid with two volume concentrations of 0.5% and 1% through circular tube with twisted tape inserts with various thicknesses at constant heat flux. It has been reported that increase in twisted tape thickness leads to an increase in friction factor (Esmaeilzadeh, *et. al.* 2014). Various experiments have been undertaken to determine heat transfer coefficients and friction factor of TiO_2/water

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nanofluid up to 3.0 % volume concentration. It has been reported that heat transfer coefficient and friction factor is higher compared to values with flow of water in a tube (Azmi, *et. al.* 2014). Computational fluid dynamics (CFD) has been employed to study the heat transfer and pressure drop characteristics of water-based Al_2O_3 nanofluid flowing inside coiled tube-in-tube heat exchangers. It has been reported that the friction factor increases with the increase in curvature ratio and pressure drop penalty is negligible with increasing the nanoparticles volume concentration and through validation it was suggested that nanofluids behave like a homogeneous fluid (Aly, 2014).

Experimental estimation of the convective heat transfer coefficient and friction factor for fully developed turbulent flow of MWCNT–Fe3O4/water hybrid nanofluids for particle loadings of 0.1 % and 0.3 % flowing through a uniformly-heated-at-constant-heat-flux circular tube has been carried out. It has been indicated that the enhancement in Nusselt number with a penalty of increase of pumping power as compared to base fluid data (Syam Sundar, *et. al.* 2014). Experimental estimation of Nusselt number and friction factor for a magnetic nanofluid, prepared by dispersing magnetic Ni nanoparticles in distilled water as a function of particle concentration and Reynolds number for constant heat flux condition in forced convection apparatus with no phase change of the nanofluid for a particle concentration range from 0% to 0.6% flowing in a tube have been carried out. Research indicate that both Nusselt number and friction factor of the nanofluid increase with increasing particle volume concentration (Syam Sundar, *et. al.* 2014).

Heat transfer coefficient and friction factor of TiO_2 nanofluid of volume concentration range from 0.0004% to 0.02% in base fluid of 40% of ethylene glycol and 60% of distilled water flowing in a double pipe heat exchanger with and without helical coil inserts have been studied experimentally. It has been reported that the heat transfer coefficient and friction factor get enhanced compared to base fluid flowing in a tube (Chandra Sekhara Reddy and Vasudeva Rao, 2014). Friction factor and heat transfer enhancement of TiO_2 nanofluids with volume fractions (1 %, 1.5 %, 2 % and 2.5 %) are suspended in water as a base fluid flow through horizontal three shapes of tubes (circular, elliptical and flat tube) having 3 mm hydraulic diameter and 500 mm length have been studied numerically. Numerical results showed that there is increase in fluid flow characteristics and heat transfer enhancement as compared with base fluid with increase in volume fraction of nanofluid (Hussein, *et. al.* 2013).

Fully developed laminar convective heat transfer and friction factor characteristics of different volume concentrations of Al_2O_3 nanofluid of particle volume concentration of 0.5 % in a plain tube and fitted with different twist ratios of twisted tape inserts have been studied experimentally. It has been found that the pressure drop increases slightly with the inserts, but it is comparatively negligible. Research showed that the use of nanofluid enhances the heat transfer coefficient with no significant enhancement in pressure drop compared to water in the range tested (Syam Sundar and Sharma, 2011).

Most of the researchers have studied the friction factor phenomenon of the nanofluid along with the heat transfer characteristics for particular application using different nanofluids. The separate study related to the effect of nanofluid in pipe and pipe fittings are not available in open literature.

In industries, many heat transfer equipments are connected in serial and/or parallel to transfer the heat as per requirements of the process/product along with furnaces, columns etc. They all are connected through pipes and pipe fittings. When nanofluid is used to enhance the heat transfer properties, it also has to flow through such pipe and pipe fittings. Thus it becomes essential to evaluate the effect of nanofluid in pipe and pipe fittings separately rather than considering along with heat transfer characteristics for a particular application. Therefore, the effect of nanofluid prepared by dispersing Al_2O_3 nano-dispersion in water in different volume concentration on friction factor of pipe and pipe fittings have been evaluated experimentally in the paper and the same of CuO nanoparticles have been evaluated in second part of the paper.

2. Experimental Setup and Procedure

Two experimental setups viz. (1) Apparatus for Pipe Friction and (2) Apparatus for Pipe Fittings are required to evaluate the effect of nanofluid on friction factor of pipe and pipe fittings experimentally. Detailed specifications and procedure for experimentation are as follow.

2.1 Apparatus for Pipe Friction

The apparatus consists of four pipes having different diameters and/or materials as shown in Figure 1.

Fig.1 Apparatus of Pipe Friction

Apparatus is fitted with G.I. pipe having 17 mm inside diameter (Pipe A), G. I. pipe having 21 mm inside diameter (Pipe B), Copper pipe having 14.5 mm inside diameter (Pipe C) and Aluminum pipe having 12.5 mm inside diameter (Pipe D). A flow control valve is provided at inlet of pipes, which enables experiments to be conducted at different flow rates, i.e. at different velocity. Tapings are provided along one meter length of pipe, so that drop of head (pressure drop) can be recorded at the manometer. Each pipe is provided with valve at outlet, which enables heads to be controlled. Discharge tank with calibration is fitted to record the discharge through pipe. A centrifugal pump of 0.5 hp circulates the liquid from tank having capacity of 170 liters to different pipes.

2.2 Experimental Procedure for Pipe Friction

1) Fill the tank with the liquid.
2) Open all the outlet valves and start the centrifugal pump.
3) Check for leakages by closing three of outlet valves alternatively for each pipe and repair the leaks, if any.
4) Open the outlet valve of the pipe to be tested.
5) Remove all the bubbles from manometer and connecting pipes.
6) Adjust outlet valve of the pipe to regulate the flow through the pipe in such a way that heads in manometer are at the readable height.
7) Note down the head drops by recording the difference of liquid level in both the limbs of manometer.
8) Record the flow rate of at the discharge tank by measuring the time required for 10 liters of liquid.
9) Record the head drop and flow rate for different flow rates of liquid from the same pipe.
10) Repeat the procedure step number 4 to 9 for other pipes.

2.3 Calculation Steps for Pipe Friction

(1) Calculation of area of pipe

$$A = \frac{\pi}{4}(D_i)^2 \ m^2 \quad (1)$$

(2) Calculation of discharge through the pipe

$$Q = \frac{0.01}{10} \ m^3/sec \quad (2)$$

(3) Velocity of fluid passing through pipe

$$V = \frac{Q}{A} \ m/sec \quad (3)$$

(4) Calculation of friction factor of the pipe

$$f = \frac{2 \times h_f \times g \times D_i}{L \times V^2} \quad (4)$$

2.4 Apparatus for Pipe Fitting

The apparatus consists of four pipes fitting viz. (1) Bend – 19 mm, (2) Elbow – 14 mm, (3) Sudden Expansion – 16 mm to 27.5 mm and (4) Sudden Contraction – 27.5 mm to 16 mm as shown in Figure 2. The set up consists of 15 mm basic piping system in which above four pipe fittings are installed. A pressure tapping is provided at inlet and outlet of each pipe fitting to record the loss of head at mercury filled manometer along with bypass valve at pump discharge to control the flow of liquid i.e. velocity of liquid. A centrifugal pump of 0.5 hp circulates the liquid from tank having capacity of 170 liters to pipe fittings. Discharge tank with calibration is fitted to record the discharge through pipe.

Fig.2 Apparatus of Pipe Fittings

2.5 Experimental Procedure for Pipe Fitting

1) Fill the tank with the liquid.
2) Fill up mercury in manometer.
3) Connect the electric supply to pump. Make sure that the flow control valve and by pass valves are fully open and all the manometer cocks are closed.
4) Start the centrifugal pump and adjust the flow rate.
5) Gradually open the manometer tapping connection of one pipe fitting. Open both the cocks simultaneously.
6) Open air vent cocks. Remove air bubbles and slowly and simultaneously close the cocks. Record the difference in monomer mercury level which gives head loss across that pipe fitting.
7) Record the flow rate of at the discharge tank by measuring the time required for 10 liters of liquid.
8) Record the difference in manometer mercury level (head loss across the pipe fitting) and flow rate at different flow rate of liquid.
9) Close the cocks and simultaneously for that fitting.
10) Repeat the procedure step number 5 to 8 for other pipes fittings one by one.

2.6 Calculation Steps for Pipe Fitting: Elbow and Bend

(1) Calculation of area of elbow

$$A = \frac{\pi}{4}(D_{elbow} \ or \ D_{bend})^2 \ m^2 \quad (5)$$

(2) Calculation of discharge through the pipe fitting

$$Q = \frac{0.01}{10} \ m^3/sec \quad (6)$$

(3) Velocity of fluid passing through pipe fitting

$$V = \frac{Q}{A} \ m/sec \quad (7)$$

(4) Calculation of actual head loss

$$h_{actualloss} = h_{\ manometer} \times 12.6 \quad (8)$$

(5) Calculation of loss coefficient of the pipe fitting: Elbow and Bend

$$K = \frac{h_{actualloss}}{V^2/_{2g}} \quad (9)$$

2.7 Calculation Steps for Pipe Fitting: Sudden Contraction

(1) Calculation of inlet of area of sudden contraction

$$A_i = \frac{\pi}{4}(D_{sc-inlet})^2 \ m^2 \quad (10)$$

(2) Calculation of discharge of area of sudden contraction

$$A_d = \frac{\pi}{4}\left(D_{sc-Discharge}\right)^2 \ m^2 \quad (11)$$

(3) Calculation of discharge through the sudden contraction

$$Q = \frac{0.01}{10} \ m^3/sec \quad (12)$$

(5) Velocity of fluid passing through inlet of area of sudden contraction

$$V_i = \frac{Q}{A_i} \ m/sec \quad (13)$$

(6) Velocity of fluid passing through discharge through the sudden contraction

$$V_d = \frac{Q}{A_d} \ m/sec \quad (14)$$

(7) Calculation of head loss due to velocity rise

$$h_v = \frac{V_d^2}{2g} - \frac{V_i^2}{2g} \quad (15)$$

(8) Calculation of actual drop of head

$$h_{acatulloss} = (h_{\ manometer} \times 12.6) - h_v \quad (16)$$

(9) Calculation of loss coefficient of the pipe fitting: Sudden Contraction

$$K = \frac{h_{actualloss}}{V^2/_{2g}} \quad (17)$$

2.8 Calculation Steps for Pipe Fitting: Sudden Expansion

(1) Calculation of inlet of area of sudden expansion

$$A_i = \frac{\pi}{4}(D_{se-inlet})^2 \ m^2 \quad (18)$$

(2) Calculation of discharge of area of sudden expansion

$$A_d = \frac{\pi}{4}\left(D_{se-Discharge}\right)^2 \ m^2 \quad (19)$$

(3) Calculation of discharge through the sudden expansion

$$Q = \frac{0.01}{10} \ m^3/sec \quad (20)$$

(4) Velocity of fluid passing through inlet of area of sudden expansion

$$V_i = \frac{Q}{A_i} \ m/sec \quad (21)$$

(5) Velocity of fluid passing through discharge through the sudden expansion

$$V_d = \frac{Q}{A_d} \ m/sec \quad (22)$$

(6) Calculation of head loss due to velocity rise

$$h_v = \frac{V_i^2}{2g} - \frac{V_d^2}{2g} \quad (23)$$

(7) Calculation of actual drop of head

$$h_{acatulloss} = h_v - (h_{\ manometer} \times 12.6) \quad (24)$$

(8) Calculation of loss coefficient of the pipe fitting: Sudden Contraction

$$K = \frac{h_{actualloss}}{V^2/_{2g}} \quad (25)$$

3. Preparation of Nanofluid

Two techniques are used to make nanofluids viz. (1) the single-step direct evaporation method, which simultaneously makes and disperses the nanoparticles directly into the base fluids and (2) the two-step method which first makes nanoparticles and then disperses them into the base fluids. In either case, a well-mixed and uniformly dispersed nanofluid is needed for successful reproduction of properties and interpretation of experimental data. For nanofluids prepared by the two-step method, dispersion techniques such as high shear and ultrasound can be used to create various particle/fluid combinations.

Two-step method has been employed to prepare nanofluid. Al_2O_3 nano-dispersion (AlO(OH)) has been purchased from M/s. Jyotirmay Overseas, Rajkot. Al_2O_3 nano-dispersion of 50 nm size has 1190 kg/m^3 density and 10 cps viscosity. The proportion of Al_2O_3 nano-dispersion to be mixed with base fluid i.e. water for different volume concentration is calculated using equation number 27 and density of nanofluid is calculated using equation number 28. For different volume concentrations, the mass of nanoparticle to mix with the water is presented in Table 1.

Table 1 Mass of Al_2O_3 Nano-dispersion to Mix with the Water for Different Volume Concentration

Volume Concentration, φ	0.001%	0.002%	0.003%	0.004%
Case Number	Case B	Case C	Case D	Case E
Mass of Al_2O_3 Nano-dispersion to be mixed with water in grams	2.023	4.046	6.069	8.092
Quantity of Base Fluid i.e. Water in litres	170	170	170	170

$$\emptyset = \frac{Volume\ of\ Nanoparticle \times 100}{Volume\ of\ Nanoparticle + Volume\ of\ water} \quad (26)$$

$$\emptyset = \frac{\frac{W_{nanoparticle}}{\rho_{nanoparticle}}}{\frac{W_{nanoparticle}}{\rho_{nanoparticle}} + \frac{W_{water}}{\rho_{water}}} \times 100 \quad (27)$$

$$\rho_{nanofluid} = \emptyset \rho_{nanoparticle} + (1-\emptyset)\rho_{water} \quad (28)$$

4. Integrated Research Methodology

The integrated methodology adopted to evaluate the effect of nanofluid in friction factor of different types of pipe and pipe fittings are as under.

1) Fill the water in apparatus for pipe friction and conduct the tests as per the experimental procedure for pipe friction. This is termed as Case A.
2) Calculate the friction factor for different types of pipes as per the calculation steps for pipe friction for water.
3) Empty the water from the tank of apparatus for pipe friction.
4) Fill the water in apparatus for pipe fittings and conduct the tests as per the experimental procedure for pipe four types of fittings one by one. This is termed as Case A.
5) Calculate the loss coefficient for different types of pipe fittings as per the calculation steps for four types of pipe fittings for water.
6) Empty the water from the tank of apparatus for pipe fitting.
7) For Case B, prepare the nanofluid by mixing 2.023 grams of Al_2O_3 nano-dispersion in water of 170 liters.
8) Perform the experimentation for Case B as per the step number 1 to 6 of integrated research methodology.
9) Perform the experimentation for Case C, Case D and Case E as per the step number 1 to 6 of integrated research methodology.
10) Compare the results.

5. Results and Discussion

Actual experimentation on apparatus of pipe friction and pipe fittings has been carried out as per integrated research methodology.

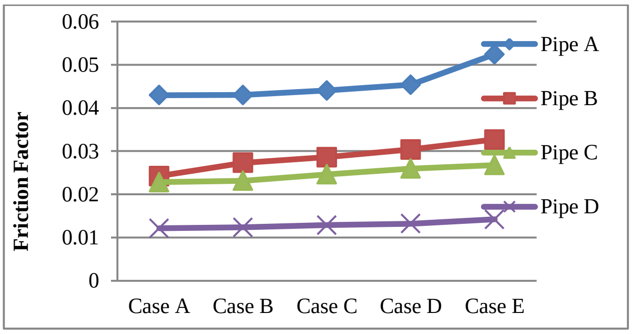

Fig.3 Result of Pipe Friction

The results for pipe friction and pipe fittings are tabulated in Table No. 2 and 3 respectively and represented graphically in Figure No. 3 and 4 respectively.

Table 2 Result for Pipe Friction

Sr. No	Case No.	Friction factor			
		Pipe A	Pipe B	Pipe C	Pipe D
1	A	0.042951	0.02423	0.02280	0.01215
2	B	0.042976	0.02730	0.02314	0.01235
3	C	0.044022	0.02860	0.02462	0.01286
4	D	0.045353	0.03037	0.02596	0.01319
5	E	0.052427	0.03266	0.02677	0.01419

The value of friction factor for different pipes increases with increase in volume concentration of Al_2O_3 nanoparticles in water. The maximum increase in friction factor for G.I. pipe having 17 mm inside diameter, G. I. pipe having 21 mm inside diameter, Copper pipe having 14.5 mm inside diameter and Aluminum pipe having 12.5 mm inside diameter for 0.004 % Al_2O_3 nanofluid is 22 %, 35 %, 17 % and 17% respectively compared to base fluid i.e. water.

Table 3 Result for Pipe Fittings

Sr No	Case No.	Loss Coefficient			
		Elbow	Bend	Sudden Contraction	Sudden Expansion
1	A	1.5062	1.5894	0.5247	0.1239
2	B	2.0083	1.6182	0.5755	0.1253
3	C	2.0628	1.7169	0.6471	0.1282
4	D	2.2031	1.7456	0.6513	0.1286
5	E	2.4565	1.8061	0.6572	0.1356

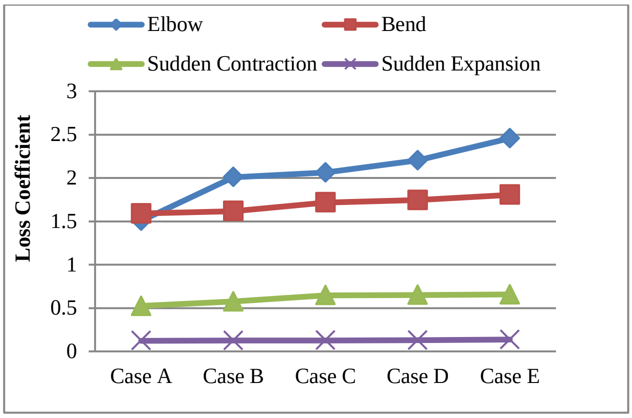

Fig.4 Result of Pipe Fitting

The value of loss coefficient for different pipes fittings increases with increase in volume concentration of Al_2O_3 nano-dispersion in water. The maximum increase in loss coefficient for elbow, bend, sudden concentration, sudden expansion for 0.004 % Al_2O_3 nanofluid is 63 %, 14 %, 25 % and 10% respectively compared to base fluid i.e. water.

Conclusions

An experimental investigation is carried out to determine the effect of various concentration of Al_2O_3 nano-dispersion mixed in water as base fluid. The volume concentrations of Al_2O_3 nanofluid prepared are 0.001 %, 0.002 %, 0.003 % and 0.004 %. The conclusion derived for the study is that friction factor and loss coefficient of different pipes and pipe fittings increase with increase in volume concentration of Al_2O_3 nano-dispersion compared to water.

Acknowledgement

The authors are extremely thankful to the staff members of Mechanical Engineering Department, A. D. Patel Institute of Technology, New Vallabh Vidyanagar for providing the useful resources and the management of the college and Charutar Vidya Mandal for providing financial support to carry out the experimentation work. The authors have also approached to GUJCOST for financial support. The authors are also thankful to the students of the college for providing their untiring support and efforts wherever needed.

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