The Effect of Using Nanofluid on the Hydrodynamic Characteristics of a Butterfly Valve

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Abstract - This study has focused on the prediction of valve flow coefficient and torque coefficient of butterfly valves when using nanofluid instead of pure water. Al_2O_3/Water is a working nanofluid. Five models were constructed and discretized according to five opening angles of 0, 20, 30, 55 and 75^o. The effects were tested for three different inlet velocities of 1, 2 and 3 m/s. For this reason, it was carried out numerical analysis using commercial CFD code FLUENT. The results revealed that here is no effect on the hydrodynamic characteristics of the butterfly valve when replacing the nanofluid instead of water.

Index Terms - Nanofluid; valve loss coefficient; torque coefficient; butterfly valve

Nomenclatures

Symbol	Name	Unit
D	Diameter	m
ϕ	Concentration	%
K_L	Valve loss coefficient	-
K_t	Torque coefficient	-
P	Pressure	Pa
Q	Volume flow rate	m^3/s.
SG	Specific gravity	-
V	Flow velocity	m/s
ϕ	Concentration	%
μ	Viscosity	Pa.s
ρ	Density	kg/m^3

Subscripts

bf	Base fluid (water)
nf	Nanofluid
p	Particle

1. Introduction

The idea behind development of nanofluids is to use them as working fluids in heat exchangers for enhancement of heat transfer coefficient and thus to minimize the size of heat transfer equipment. Nanofluids have been found to possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water[1-7]. In order to apply these enhancements, the dependent parameters due to using the nanofluids such as wear and pressure losses must be investigated. Wear effects can deteriorate the flow passages or the components at these passages while the increase in the pressure drop can overcome the benefits of using nanofluids. Valves are the parts which have the significant fraction of the total pressure losses. Butterfly valves are frequently used as control valves for relatively low pressure drop applications and have been widely used as control valves because of the economics involved.

Butterfly valves permit high flows with relatively low pressure loss from the valves. At valve with opening angles higher than 70 degrees, the pressure drop of a butterfly valve is too low to produce any noteworthy effect on the flow or the energy loss of the flow system[8].

This work investigates the effect of using nanofluids on the hydrodynamic characteristics of the butterfly valves using the computational methods.

2. Literature review

The enhancement of heat transfer by convection occupied noteworthy fraction of the researches using nanofluids as working fluid according to the applications. Pressure drop in nanofluids was examined by many researchers. Xuan [9], He [10] and Duangthongsuk [11] claimed that the dilute nanofluid incurs almost no extra penalty of pump power while Arani [12] mentioned that the pressure drop of nanofluid was slightly higher than that of the base fluid and increases as volume concentration increases. Sajidi [13] achieved maximum pressure drop about 25% higher than that of pure water which was occurred in the highest volume fraction of nanofluid (0.25%) at Reynolds number of 5000.

Fotukian [14] in his experimental work remarked that dilute nanofluids increase the pumping power. His measurements on CuO/water nanofluid revealed that the pressure drop is increased about 20% for nanofluid with 0.031% volume concentration. Fotukian [15] showed, next that the pressure drop for the dilute nanofluid was much

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higher than that of the base fluid. It is observed that the pressure drop of nanofluid with 0.135% volume concentration showed 30% increase at Reynolds number of 20,000 compared to pure water.

Razi [16] showed that there is a noticeable increase in pressure drop of nanofluid with 0.2% wt. particle concentration compared to that of pure oil flow reached 12% for round tube and 58% for flattened tube.

Sundar [17] remarked that the friction factor of 0.5 vol.% of Al2O3 nanofluid with a twist ratio of five was 1.096 times higher as compared to the flow of water in a circular tube.

Recently, Arani [18] introduced a new correlation to calculate the friction factor for flow of TiO_2–water nanofluid. Pressure drop increases by changing the Reynolds greater than about 30,000 while, for a lower Reynolds number, all nanofluids have a similar pressure drop.

Although the nanofluid is actually a two-phase fluid in nature, the results show that the nanofluid behaves more like a pure fluid than a liquid–solid mixture, [11]. His results show that the conventional single-phase pressure drop correlation may be used to predict the pressure drop in a very low concentration nanofluid.

The aim of this paper is to investigate the response of the characteristics of butterfly valves due to using Al2O3/water nanofluids as working fluid in the system.

3. Mathematical formulation

3.1. Problem statement

The schematic of the investigated butterfly valve is presented in Fig. (1). The geometry of the duct has diameter of 0.15 m with valve upstream and downstream distance of 2D and 6D, respectively. These ratios were recommended by [19]. The nanofluid enters the duct with uniform velocity and is affected only by the duct and valve conditions. The nanofluid is incompressible and the flow is turbulent. Also, it is assumed that the liquid and solid are in equilibrium, and they flow with same velocity. The resultant mixture may be considered as a conventional single phase fluid. Furthermore, the assumption of single phase for a nanofluid is validated to an extent by [20-23].

The experiments were done for five openings angle; 0, 20, 30, 55 and 75° while three velocities 1, 2 and 3 m/s were tested.

Five models for each opening angle were constructed and discretized according to [24, 25].

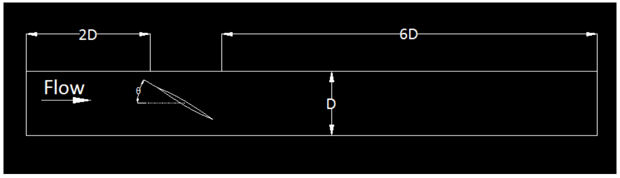

Fig. (1). Butterfly valve in the flow domain.

3.2 Governing equations

The single-phase model, which has been used frequently for nanofluids, is also implemented to compare its predictions with the mixture model. The following equations represent the mathematical formulation of the single-phase model by [20-23]:

Conservation of mass:

$$div\left(\rho\bar{V}\right)=0 \quad [1]$$

Momentum equation:

$$div\left(\rho\bar{V}\bar{V}\right)=-gradP+\nabla.\left(\mu\nabla\bar{V}\right)+S_m \quad [2]$$

The compression work and the viscous dissipation are assumed negligible in the energy equation; the source/sink terms S_m in Eq. 2 represents the integrated effects of momentum exchange with the base fluid, and they are equal to zero in the case of single-phase model.

3.3 Nanofluid properties

In the absence of experimental data for nanofluid densities, based on nanoparticle volume fraction, the following parameters were used as reported by [26-28] and others.

Density:

$$\rho_{nf} = \phi.\rho_p + (1- \phi)(\rho_{bf}) \quad [3]$$

Viscosity

$$\mu_{nf} = \mu_{bf} \,.\, (1 + 2.5\, \phi) \quad [4]$$

where, μ_{bf}, ρ_p and φ are basefluid viscosity, nanoparticles density and volume fraction of nanoparticles, respectively.

The results of [29] showed that use of the viscosity models for nanofluids gives different values compared with the use of the measured data, by about 2–3%. Properties of Al2O3 nanoparticles are used in this study.

3.4 Data analysis:

In order to calculate Reynolds number (Re), Eq. (5) is applied.

$$Re = \rho_{nf}\,.\, V \,.\, d_h/ \mu_{nf} \quad [5]$$

Where d_h is the inner diameter of the passage. ρ_{nf} and μ_{nf} are density and viscosity of nanofluid respectively while V is the flow velocity.

- Valve Loss Coefficient

The fluid in a piping system passes through various valves, bends, elbows, inlets, exits, enlargements, and contractions, in addition to the pipes. These components interrupt the flow of the fluid and add additional losses because of the flow mixing and separation. Therefore these losses, called the valve loss coefficient, is determined experimentally and quantified as another representation of relation between pressure difference, fluid density and fluid average velocity,[30];

$$K_L = \frac{\Delta P}{0.5.\rho\,.V^2} \quad [6]$$

-Torque coefficient

The coefficient Kt is a parameter commonly used in valve sizing in practical design because pressure design is always given as one specification.

$$K_t = \frac{T}{\Delta P.d^3} \quad [7]$$

The pressure loss is obtained by measuring separately the frictional loss of the pipe (without valve for each concentration) between points at 2D upstream, and 6D downstream of the valve. The net pressure difference ∆P can then be obtained by subtracting the frictional loss from the pressure loss of the valve.

4. Results and discussions

As confirmed by Fotukian [15-18] that the pressure drop of nanofluid was much higher than that of the base fluid. Figure (2) shows the variation of pressure drop with the valve opening angles.

With the increase in volume concentration, the density and viscosity increases and hence they cause an increase in the pressure drop as shown in Fig. (2). The increase ratios are 0.29, 1.4, 2.9 and 14.8% for concentrations of 0.1, 0.5, 1 and 5%, respectively. These ratios remain nearly constant at all inlet velocities and same opening angles.

Figure 3 is demonstrating the change of kinetic energy with opening angles of the valve. The kinetic energy $(1/2.\rho.V^2)$ of the nanofluids is the same with opening angle as it changes with concentration of the nanofluid. This is due to the change of the density of the nanofluid which is a function in the concentration, Eq. [3].

The change in the pressure difference is approximately the same with kinetic energy change. This is clearly presented in Fig. (4) which displays the variation of the valve loss coefficient (K_L) with the valve opening angle. Valve loss coefficient yields the same trend that exhibits when the fluid is pure water.

Torque produced on is valve is presented in Fig. (5). It is clear that the torque of a butterfly valve increases as the valve is closed. For specified opening angle, the torque is increasing with the inlet velocity. However, further increase will arise when nanofluid with higher concentrations is used instead of pure water. As a result, when applied to the Eq. [7], the torque coefficient, remain unchanged because the change in the ∆P shown in Fig. 2.

Figure (5) is the relation of torque coefficient changes with valve opening angle. The predicted curves express approximately the change of torque coefficient with the valve opening in the experiments. The peak of the torque coefficient occurs at valve openings in the vicinity of 20o which was confirmed by [31].

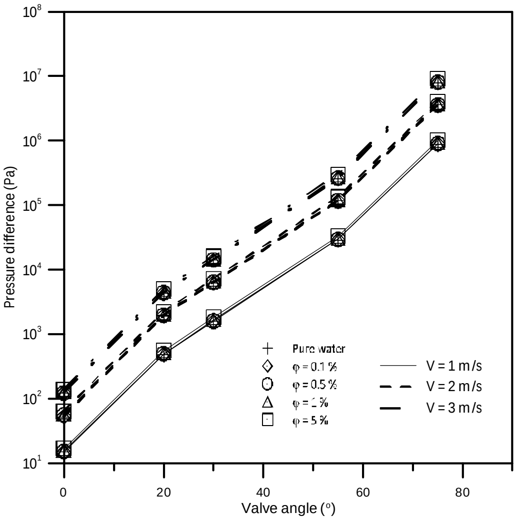

Fig. 2 Variation of pressure drop with valve opening angle for different velocities.

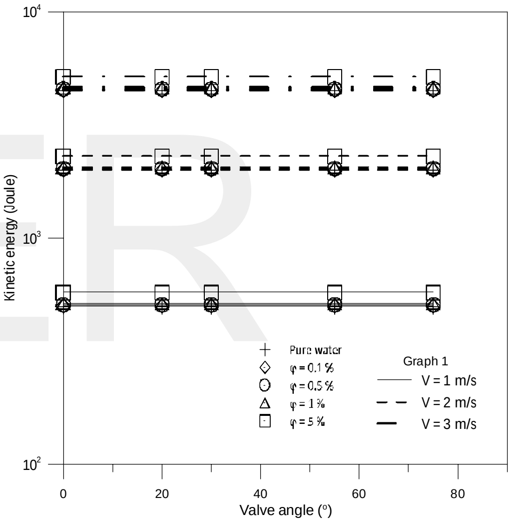

Fig. 3 Variation of kinetic energy with valve opening angle for different velocities.

5. Conclusion

It is clear from our results that neither the valve loss coefficient nor the valve torque coefficient is affected by using the nanofluid with any concentration instead of pure water. Changing the working fluid will safely have no effect on the system operation and performance. Moreover, selection criteria for the butterfly valves that will employ nanofluid will remain alike.

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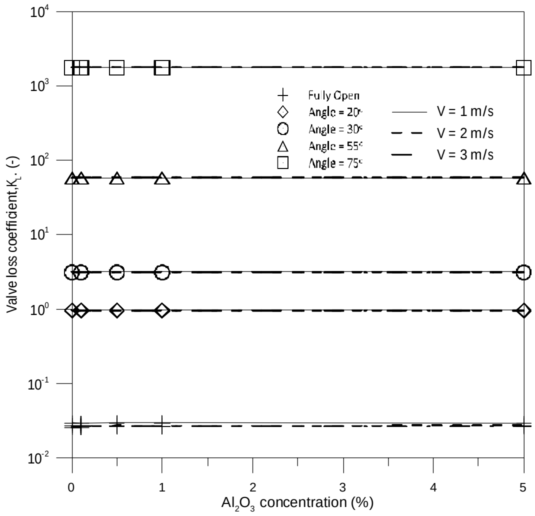

Fig. 4 Variation of valve loss coefficient (K_L) with concentration.

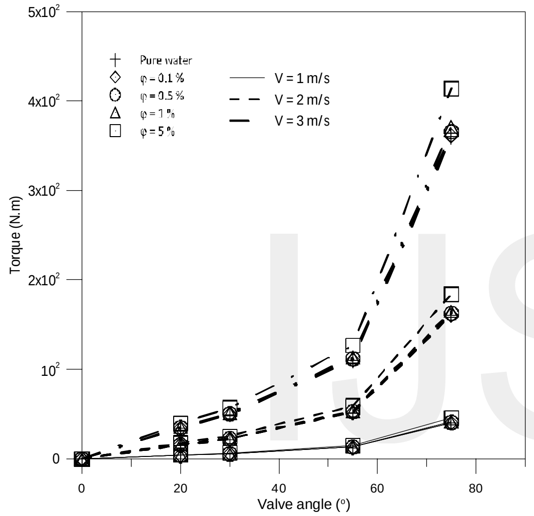

Fig. (5) The relation between the toruq and valve opening angle for different velocities

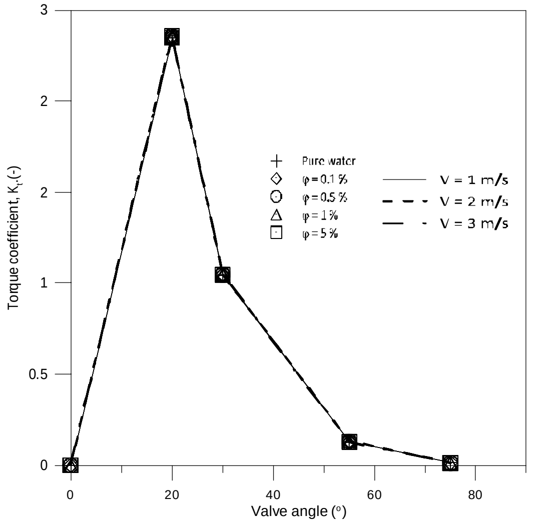

Fig. (6) The varaiton of torque coefficient (K_T) with valve angle for different velcoties.

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