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FUMED SILICA FIBER AS A NEW DRAG REDUCING AGENT FOR AQUEOUS MEDIAS FLOWING THROUGH PIPELINES

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ABSTRACT

In the present study, Fumed silica powders were presented as a new effective Drag Reducing Agent. The effects of using various concentrations of fiber and flow rate on increasing the flow in pipelines were investigated in a fully developed turbulent flow. The effects of pipe length to pipe diameter (L/D) on drag reduction were also investigated. A built experimental rig with different diameters of PVC pipes was used in order to investigate the performance of fumed silica fiber as drag reducing agent. The experimental results showed that the fume silica have a great ability to act as a good drag reducing agent in aqueous media. The addition of 600 ppm of the fumed silica to the main flow was enough to reach a maximum reading of the percentage drag reduction up to 40 % this maximum percentage was achieved in 59 L/D at Re equal to 22470. The drag reduction decreases as the Re exceeds 22470. These experimental results show that the fumed silica powder performed as a good DRA.

Keywords: DRA, drag reduction, fibers interaction, turbulent flows, fiber flexibility.

INTRODUCTION

The drag reduction in pipelines and in others devices such as heating and cooling systems during the transportation of fluids was identify through pressure drop. This pressure drop causes more pumping power requirements. When fluid transmission occurs in long distance and in high volume, energy saving become the most important issues. The concept of drag reduction allows pipelines to be operated at a lower pressure, reducing energy costs and more production with less energy consumption. Drag reduction is achieved by addition of drag reducing agent (DRA) which is polymers, surfactants and fibers. Many researchers through their experimental work have proved the capability of these DRA. Each of these DRA has their advantages and disadvantages. Drag reducing fibers are well known as safest and cheapest DRA compare to surfactants and polymer which some of the surfactants caused problems to environment in high consumptions. The drag reduction in a present of fibers occurs when the concentration was enough for fibers interaction to occur but below a critical concentration. Most of the researchers have a good agreement that the key to understand the mechanism behind the drag reduction of fibers additive is the interaction of fibers in core region of turbulent and the orientation distribution of fibers (Abdul Bari *et al*., 2008). The shear rate of fluid around fiber and the length scale of flow are the key factor for determining the orientation distribution of fibers, while the fiber velocity and the fiber Stokes number have marginal influence on the orientation distribution of fibers (Jianzhong *et al*., 2004). The flexibility of fibers also becomes one of the most discussed topics to explain the drag reduction mechanism (Luettgen *et al*., 1991). Depending on the types and properties of fibers, the addition of fibers to a flow can have either a stabilizing or a destabilizing effect (Vaseleski *et al*., 1974). For a fiber suspension with hydrodynamic interactions, the shear stress disturbance induced by the misalignment of the fibers is the main driving term behind the decrease of the flow instability. Thus, the normal stress disturbance acts as a destabilizing factor (Azaiez, 2000). Flexibility of fibers and its interactions with the vortexes in flows has been reported as a reason of drag reduction in turbulent flow (Zhu and Peskin, 2007). Lin *et al*. (2006) conducted an experiment through iteration of fiber distributions and interaction in turbulent channel flow. They found that in a present of fibers, the relative turbulent intensity and the Reynolds stress is smaller than in Newtonian flow without fibers. These phenomena interpreted that the fiber suspensions capable on suppressing the turbulent flow. Barresi (1997) showed that the turbulence suppression can be attributed through the facts that in dense suspensions a significant fraction of fluid does not depend only on its concentration, but also its movements with the particles. These phenomena can be explained through action of surface friction and the work of viscous forces which arise as an effect of sudden changes in the fluid velocity that accompany any collision.

MATERIALS AND METHODS

Fumed Silica powder

Fumed silica which is product of Sigma-Aldrich Sdn.Bhd was used as an investigated material in this experiment. Table 1 shows the properties of fumed silica powders.

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Table 1. Properties of fumed silica.

Particle size, (µm)	Length (µm)	Surface area (m^2/g)	Density (g/cm^3)	Molecular weight (g/mol)
0.011	0.1 - 0.2	255	2.2	60.09

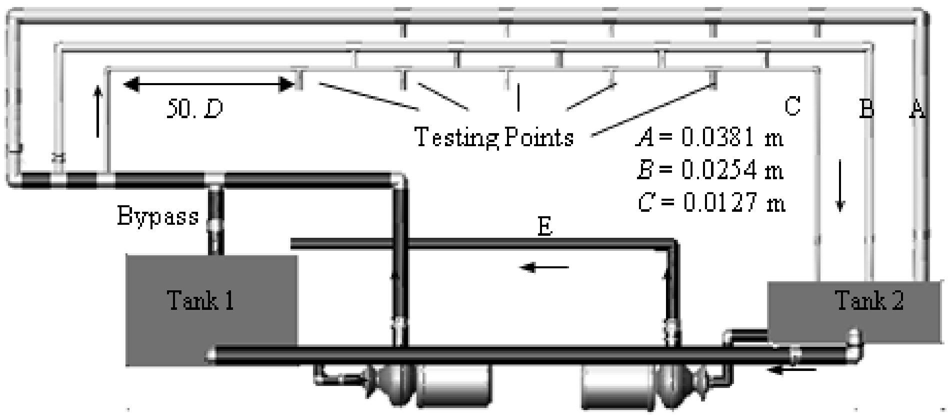

Fig.1. The Experimental Rig.

Experimental systems

The experimental system consisted of build up rig, Baumer differential pressure gauge and Minisonic P flow meter. Baumer pressure gauge was used to detect the pressure drop and Minisonic P flow meter was used to measures the flow rate of fluid through pipes. The rig is consisted of three different internal diameters of pipes as shown in figure 1. Each pipe was completed with testing section in which these testing points are connected with the Baumer differential pressure gauge through portable rubber tube. The system consist pipes with 0.0127m, 0.0254m and 0.0381m inside diameter and the length of 2 m made from transparent PVC pipe to permit visual observation of flow pattern in the future was used as the test section. Each pipe divided into four pressure testing sections with a distance equal to 0.5 m. The first pressure testing point for each pipe was located about 50 times pipe diameter (50.*D*) of the testing pipe as shown in figure 1. This is to ensure the turbulent flows are fully developed before the testing point.

The flow rate of fluid in pipelines was measures by Ultraflux Portable Flow meter Minisonic P in which this ultrasonic flow measurement was sensitive with small changes in flow rate as low as 0.001m/s. The purpose of using this exterior portable ultrasonic measurement is to avoid any disturbance might happen in the flow pattern. Baumer Differential Pressure Gauges were used to detect the pressure drop in pipelines with maximum differential pressure readings up to 0.16bar.

Experimental procedures

The experimental work was carried out in 1.5m length and 00381m diameter pipe. The length to diameter (L/D) ratio was 59. The data of pressure drop for water alone are initially used in the calculations of drag reduction in which the drag reduction in pipes is defined as:

$$\text{Reduction (\%)} = \left(1 - \frac{\Delta P_a}{\Delta P_b}\right)100 \qquad (1)$$

Where; ΔP_b is pressure drop before and ΔP_a is after the addition of fibers solution. Fumed silica powders were tested and circulated in the experimental rig each time with different concentration. The addition concentrations were 200, 300, 400, 500 and 600 ppm. For each concentration, different flow rates are tested for the solution and pressure drop readings are taken and compared with the readings of the flow of the pure water flowing in the same pipelines.

RESULTS AND DISCUSSION

The initial data were presented in term of friction factors and compared with friction factor correlation of Blasius and Virk as shown in figure 2.

Friction factor is defined as below:

$$f = \frac{2\tau_w}{\rho V^2} \qquad (2)$$

$$\tau_w = \frac{D\Delta P}{4L}$$

The Blasius equation is defined as (Yunus and Cimbala, 2006):

$$f = 0.0791 Re^{-0.25} \qquad (3)$$

and Virk's asymptote is defined as (Virk et al. 1970):

$$f = 0.59Re^{-0.58} \tag{4}$$

Whereas the Reynolds number in pipe is defined as:

$$Re = \frac{\rho VD}{\mu} \tag{5}$$

Moreover, the friction factors in pipes based on laminar flow are defined as:

$$f = \frac{16}{Re} \tag{6}$$

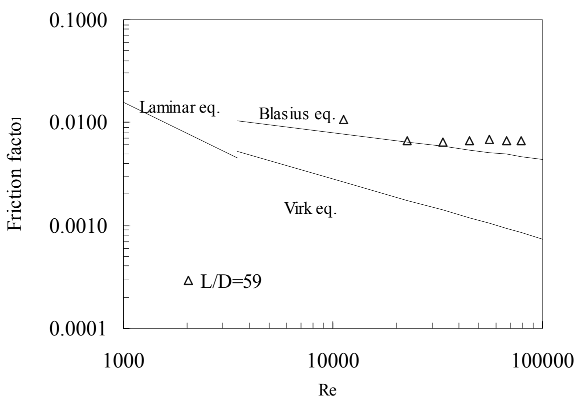

Fig. 2. Relationship between friction factor and Re of water in PVC pipe.

The experimental data of water flow are plotted in figure 2 and compared with Blasius asymptote for liquids additive free flow in pipelines. The figure included both the laminar flow and Virk maximum drag reduction flow asymptotes. It is clearly shown that the values of the additive-free water flow in pipes used in the present experiment lies near the Blasius asymptote which will give the experimental work a good starting point towards more accurate readings.

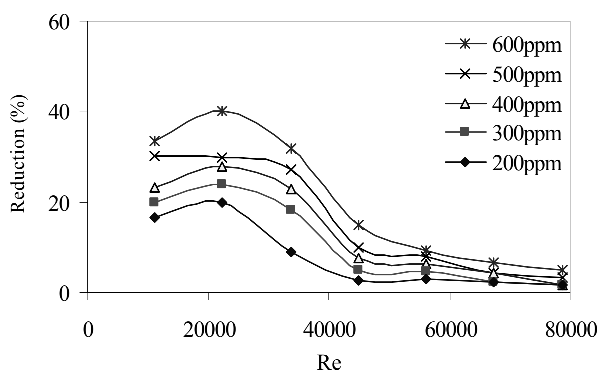

Fig. 3. The relation of drag reduction with Re for fumed silica in 59 L/D.

Figure 3 shows the relations of drag reduction with Reynolds number (Re) in different concentration of solution. The range for drag reduction likely to occurred is within the range of Re = 12000 and Re = 33000. At this range, the maximum drag reduction achieved is 40% at highest concentration which is 600 ppm and the minimum is 9 % observed at 200 ppm. It is clearly shown that the drag reduction is initially increases as the Re increases but begin to decrease after exceed 21000. At high Re, the drag reduction decreases and become almost constant which is in a range of 3% to 15%. This behavior may be due to the change in the degree of turbulence compatibility with the additive type and concentration which reaches certain optimum value where maximum percentage of drag reduction are achieved and in certain parts, increasing the degree of turbulence may be more than the optimum value which will lead to a less effective action.

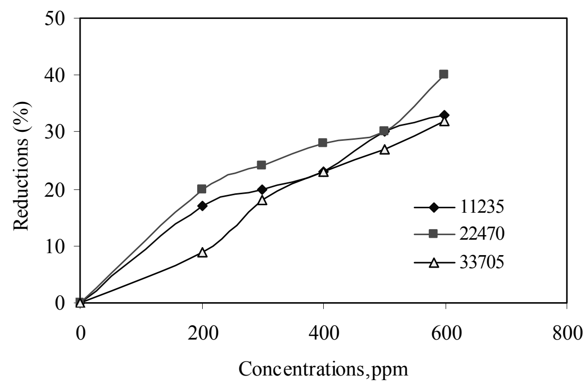

Fig. 4. Relations of drag reduction with concentration for Re at 11235 to 33705.

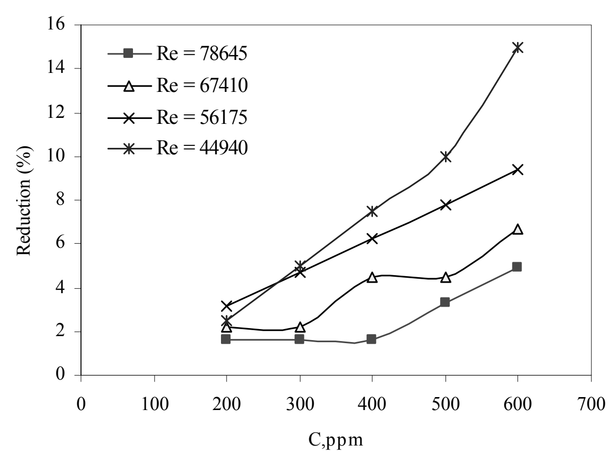

Fig. 5. Relation of drag reduction versus concentrations for Re at 44940 to 78645.

Figure 4 and 5 shows the comparison of three different Re of drag reduction versus concentration of solution. In figure 4; the first drag reduction was observed is at Re equal to 11235. From the figure, it can be noticed that the drag reduction continuously increases until Re reached 22470 and started to decreases but still in a good performance until 33705 of Re. From figure it is clearly shown that each concentration of solution at 22470 Re obtained the highest drag reduction compare to others. At 600ppm concentrations, the average drag reduction was achieved for all Re is 35%, at 500ppm is 29%, at 400ppm is 25%, at 300ppm is 21% and at 200ppm is 15% (Fig. 5). Figure 5 shows the relations of drag reduction with different concentrations of solution at Re equal to 44940, 56175, 67410 and 78645. From figure, it shows that the drag reduction decreases as the Re increases. The highest drag reduction was achieved based on that figure is 15% and the lowest is 2%. This results show that, the DRA's concentration at 600 ppm was not appropriate when operated at Re higher than 78645. From the results shown by figures 4 and 5, it is easy to notice that by increasing the additive concentration the performance of the drag reducer will be better and that may be due to the increase of the turbulence spectrum that will be under the drag reducer effect which will balance the increasing degree of turbulence caused by increasing the flow rate (Re), another words, the drag reduction occurred probably caused by the rheology properties and interaction of fibers in flow. Flexibility of fibers important to form a network to surpassed the turbulent flow. The reductions of drag-reduction at high Re are probably caused by the concentration of fiber solution were not longer appropriate to surpass the high degree of turbulent flow. In order to maintain the drag reduction in flow, the concentration of fiber should be added.

CONCLUSION

It is proven that the solubility condition for any material to be classified as drag reducing agent is no longer dominating. Fumed silica powders showed high ability to increase the flow in pipelines carrying water by reducing the drag caused by turbulence. Maximum percentage of drag reduction achieved is 40% and the overall experiments which mean 40% power savings by the addition of only 600 ppm fume silica powder.

Notation

ρ solvent density	Re Reynolds number
μ absolute viscosity of solvent	L/D pipe ratio
D internal diameter of pipe	ΔP pressure drop in pipe
L pipe length	f friction factors
V means velocity of solvent	τ_w wall shear stress

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