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ORIGINAL RESEARCH ARTICLE

DRAG REDUCTION WITH POLYMER MIXTURES IN PIPES OF DIFFERENT DIAMETERS

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ABSTRACT

Transporting crude oil and other fluid in pipelines of different sizes over long distances in process industries require high amount of energy which results to high cost of installing pumping stations and maintenance. Addition in part per million (ppm) of high molecular weight polymeric solution reduce such cost. The effect of pipe diameter, oil input volume fraction and flow rate (superficial velocity) on drag reduction (DR) in horizontal oil-waterflows was investigated in unplasticised polyvinylchloride (uPVC) horizontal pipe with two different pipe diameters (0.012 and 0.02 m IDs). The two liquids used were diesel oil (ρ = 832 kg/m^3, μ = 1.66 cP) and water (ρ = 1,000 kg/m^3, μ = 0.89 cP) as test fluids at ambient conditions (25°C, 1 atm). Partially hydrolyzed polyacrylamide (HPAM; magnafloc 1011), polyethylene oxide (PEO) and Aloe Vera Mucilage (AVM) separately, as well as mixture of HPAM-AVM and PEO-AVM at different oil input volume fraction (δ_o; 0,0.25, 0.5, 0.75 and 1) and flow rate (Q; 0.65, 1.28, 1.90 and 2.46 m^3/hr) were used. The master solution of 2,000 ppm, 2,000 ppm and 20,000 ppm for HPAM, PEO and AVM respectively and their respective mixtures were used to achieve the required concentrations. Mercury U-tube manometer was used to measure the pressure drop. DR of 62%, 65%, 54% for HPAM, PEO and AVM; 69 and 71% for HPAM-AVM and PEO-AVM respectively at mixing ratio of 3:1 and 1:19 in 0.012 m ID. Also, DR of 58%, 62%, 43% for HPAM, PEO and AVM; 67% and 68% for HPAM-AVM and PEO-AVM respectively in 0.02 m ID were obtained at the same condition. The pressure drops observed in the smaller pipe (0.012 m ID) was higher than that of the larger pipe diameter (0.02 m ID). From the experimental results, DR decreased with increase in the pipe diameter at the same conditions. This result implies that, DR in oil-water pipeline flow is a function of oil input volume fraction, superficial velocity and pipe diameter

1.0 Introduction

The turbulent pipeline transportation of two immiscible liquids (oil-water) is always encountered in chemical and petroleum industries, which requires large amount of energy because of the pressure drop experience. Turbulent structures (eddies) of different sizes are formed during the turbulent liquids pipeline flow, which increase the pressure drop and dissipate pumping energy (Yusuf et al., 2013; Abdulbari et al., 2014; Edomwonyi-Otu and Angeli, 2014, 2019). The large decrease in pressure drop by addition of small amount of polymers in parts per million (ppm) is referred to as percentage drag reduction (DR) (Sellin et al., 1982; Bewarsdorff and Gyr, 1995; Gimba et al., 2018). One of the first industrial applications of DR was the Trans-Alaska pipeline system (1300 km, 1.2 m ID) in 1979, where 10 ppm of oil-soluble polymer was used to increase the flow rate. Drag reduction of 50 % was achieved, which eliminated the need of installing additional two pumping stations to boost the throughput from 1.45 to 2.1 million barrel per day. Other application includes marine and biomedical system, crude oil pipeline transportation over a long distances, irrigation, floodwater disposal and sewage, drilling of oil from reservoir, firefighting, Extraction, filtration, heat and mass transfer application (Marmy et al., 2012; Gimba et al., 2017). It is also now being suggested for transportation of drinking water because of its harmless properties (Edomwonyi-Otu and Adelakun, 2018).

The parameters responsible for pressure drop in oil-water pipeline flow include pipe diameter, superficial velocities (mixture velocities), volume fraction of each phase (oil and water), density, and viscosity of the fluids at constant pressure and temperature (Abubakar, et al., 2015). The effect of pipe diameter on drag reduction in pipeline flow using drag reducing polymers (DRP) was studied by many researchers (Lescarboura et al., 1971; Virk, 1975; Interthal and Wilski, 1985; Ahmad et al., 2009; Karami and Mowla, 2012; Yusuf et al., 2013; Abubakar et al., 2015a; Edomwonyi-Otu et al., 2016).

Abubakar et al., (2015b) studied the drag reduction on oil-water flow in relatively large pipe diameter with polymer concentration of 40 ppm and pipe diameter of 0.0747 m ID. Mixture velocities ranging from 0.1 – 1.6 m/s and 0.05 – 0.9 oil input volume fractions were used. They compared their results with that of Abubakar et al., (2015a), where they used pipe diameter of 0.306 m ID at the same conditions. Maximum DR of 51% in 0.0747 m ID and 64% in 0.0306 m ID at oil input volume fraction of 0.05 and mixture velocity of 1.6 m/s were achieved by (Abubakar et al., 2015b). They (Abubakar et al., 2015b)also concluded that, DR increased with decrease in pipe diameter. Karami and Mowla (2012) also studied DR of three drag reducing polymers in two galvanized iron pipes of 0.0254 and 0.0127 m IDs at the same conditions. They also reported that the drag reduction decreased with increase in pipe diameter for all DRP used. Ahmad et al., (2009) investigated the effect of Okra mucilage on DR in different size of pipes (0.015 and 0.025 m ID) in turbulent water flow. They observed that, DR increased (50 – 71%) with decrease in the pipe diameter (0.025 – 0.015 m IDs) at the same conditions. They suggested that, decreasing the pipe diameter means increasing velocity inside the pipe, which results to high degree of turbulence. The high velocity observed in the smaller pipe brings good interaction between the additive and the turbulent structure (eddies), which subsequently brings about the drag reduction effectiveness. This agreed with the work of Karami and Mowla (2012). Interthal and Wilski (1985) were among the first to publish the effect of drag reducing polymers and pipe diameter on DR. They (Interthal and Wilski, 1985) also reported that DR increased (66 – 80%) with increase in pipe diameter (0.003 – 0.014 m ID) and then fall to 76% at the highest pipe diameter (0.03 m ID), showing lack consistency in their results. Lescarboura et al., (1971) investigated DR in crude oil (single phase) pipeline flow with 8 and 32-inch ID and length of 28 and 32 miles, using polymer concentration of 300, 600 and 1000 ppm respectively. They achieved DR of 16, 21 and 25% (8-inch ID) and 16, 16.2 and 16.9% (32-inch ID) at the same conditions. They concluded that DR decreased with increase in pipe diameter and decrease in velocity.

Despite the available works done in open literature, the influence of pipe diameter on drag reduction is still scanty. More data were needed to develop models for the accurate prediction of drag reduction in horizontal oil-water pipeline flow than is currently available. Hence, the motivation of this work is to provide more data on the study of the effect of pipe diameter on drag reduction in horizontal oil-water flow system using aloe Vera mucilage (AVM), polyethylene oxide (PEO) and hydrolyzed polyacrylamide (HPAM) as well as their mixture (HPAM-AVM and PEO-AVM).

2. Experimental Set-Up

2.1 Description of the flow facility

The schematic diagram of the experimental set-up is shown in Figure 1. The flow facility is divided into: the handling section, pumping or regulating section and test section. The handling section consists of three tanks where the fluids are stored: the oil, water and separator tanks have capacity of 200, 200 and 220 liters respectively. The separator tank allows settling under gravity where water is drain through the bottom opening and the oil is recycled. In the regulating or pumping section, 0.012 and 0.02 m ID unplasticised polyvinylchloride (uPVC) pipes are each connected to water and oil tanks. The centrifugal pumps (model Jet 102M/N.31227) with maximum flow rate of 65 l/min each were used to circulate the test fluids into the test section. The globe valves were used to regulate the flow rates which were measured with variable area flow meters (LZM-20J; ±5% accuracy), separate for each fluid. The water flow meter has maximum flow rate of 100 liters per minute (LPM). The flow meter was calibrated before the commencement of experiments. The injection port for the polymer master solution is located by the side of the water pipeline before the Y-junction. The new Era-programmable peristaltic pump (model NE-9000; ±2% accuracy) was used to inject the polymer master solution into the water phase. The test section was made up of straight acrylic pipe of 0.012 and 0.02 m ID and 140 times the diameter of the pipe (140D) long from the Y-junction to the second pressure port. The pressure taps were created by making small holes at the bottom of the acrylic pipe walls at the distance of 140D which provides fully developed flow in the test section.

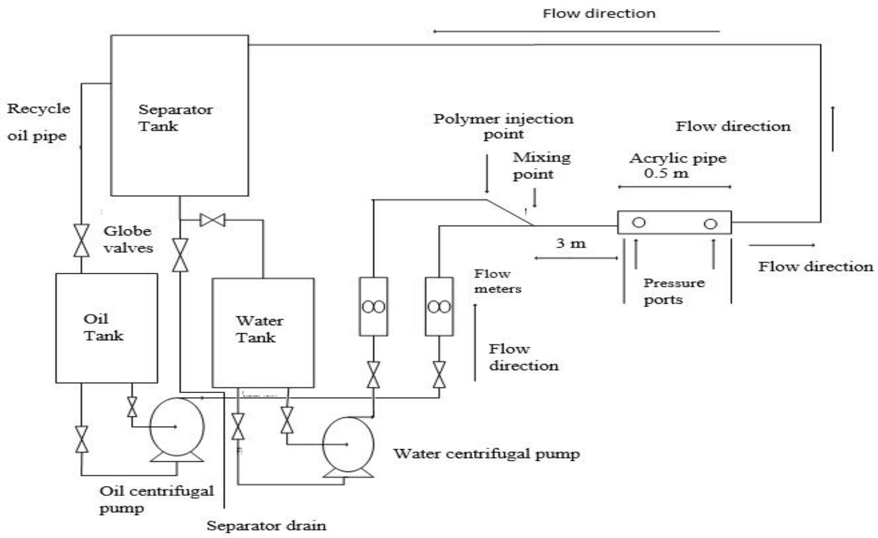

Figure 1: Schematics of experimental set-up of flow facility

2.2 Polymer preparation

The polymers used are partially hydrolysed polyacrylamide, HPAM (Magnafloc 1011) manufacture by BASF chemicals 10 × 10^6 g/mol, polyethylene oxide (PEO) manufacture by Sigma-Aldrich with average molecular weight of 8 × 10^6 g/mol, and Aloe Vera mucilage (AVM) extracted from Aloe Vera plant. All the polymers are water soluble and were used without further purification. The polymers solutions were prepared individually first, before the polymer mixture

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solutions were prepared. A master solution of 2,000 ppm of each of the synthetic polymer was prepared as follows. 10 g of each of the polymer powder was measured using weighing balance (Kerro, BLC 3002) and gently spread over 5 liters of water surface and stirred for 3 hours with a mechanical stirrer (Gilverson, L28) at a very low speed (to avoid degradation of the polymer) for the mixture to be completely homogenized. The stirred solution was left for 12 hours to ensure complete dissolution of the polymer particles and removal of trapped gas bubbles to form the master solution (Gimba et al., 2018;Edomwonyi-Otu and Angeli, 2014, 2019). Aloe Vera leaves were harvested from a garden and washed thoroughly with tap water. The leaves were then cut vertically on both sides and soaked in tap water for 10 minutes, to remove the Aloin within them. The leaves were then peeled and the Aloe Vera mucilage (AVM) was extracted by scraping and sieving the gel from the aloe leaves (Gimba et al., 2017). Aloe Vera leaf contains about 98% water while the remaining 2 % is the AVM (Bozzi et al., 2007; Davis, 1997). Master solution of AVM was prepared with 20,000 ppm. For the polymer mixture preparation, the total concentration (TC) of 30 ppm and 400 ppm for the mixture (HPAM-AVM and PEO-AVM) were because one of the polymers in the mixture gave maximum DR at that concentration (Reddy and Singh, 1985). 250 milliliters of 20,000 ppm of AVM master solution was measured and diluted with 10,000 milliliters of water to achieve 500 ppm.1500 ppm of the synthetic polymers (HPAM and PEO) was mixed with 500 ppm of AVM and stirred for 3 hours and the stirred solution was left for 12 hours to form a master solution of 2000 ppm for the polymer mixtures (Reddy and Singh, 1985; Malhotra et al., 1988). It was injected into the water phase at specific flow rate to achieve the required concentration in the water flow line.

2.3 Experimental procedure

The flow meters and injection pump were tested before running the experiments to ensure accurate delivery of the required amounts of oil and water into the test section, and the polymer master solution into the water phase. The experiment was carried out in horizontal pipe diameter of 12 mm ID and length of 140 times the diameter of each of the pipe at ambient conditions (25 °C, 1 atm). The U-tube manometer (Pyrex) was used for the pressure drop measurement. Each experimental run was repeated three times and the average of the pressure drop measured before and after the addition of the DRAs. HPAM, PEO, AVM, HPAM-AVM and PEO-AVM were tested at different oil input volume fraction (δ_o) and superficial velocity (Us). The total concentration (TC) of 30 ppm and 400 ppm for HPAM, PEO, Aloe Vera mucilage (AVM) as well as their mixtures at flow rate of 30 l/min was tested.The optimal polymer concentration (30 ppm for HPAM and PEO and 400 ppm for AVM) and 30 l/min were obtained from our preliminary single phase water experiments (Gimba et al., 2017 and 2018). The optimal concentration was selected to be the total concentration (TC) of the polymer mixture (Reddy and Singh, 1985). The mixing ratio of 3:1 and 1:19 were used. The superficial velocities investigated range from 0 m/s to 1.68 m/s for 0.020 m and 0 m/s to 4.67 m/s for 0.012 m ID. They superficial velocity and the oil input volume fraction (δ_o) was calculated from the Equations 1 - 4. The pressure drop was recorded and used for calculation of drag reduction as defined by Equation 5;

$$U = \frac{Q}{A} \tag{1}$$

$$Usw = \frac{Qw}{A} \tag{2a}$$

$$Uso = \frac{Qo}{A} \tag{2b}$$

$$\delta o = \frac{Qo}{Qo + Qw} \times 100\% \tag{3}$$

$$\delta w + \delta o = 1 \quad (4)$$

$$DR = \frac{\Delta P_{WO} - \Delta P_W}{\Delta P_{WO}} \times 100\% \quad (5)$$

Where; U is the average velocity of the fluid in a pipe (m/s), Usw and Uso are the superficial velocities of water and oil (m/s). A is the cross-sectional area of the pipe (m), Qw and Qo are the flow rate of water and oil (m3/s) and δw and δo are the input volume fraction of water and oil. ΔP_{WO} and ΔP_W is pressure drop of the fluid without and with DRAs (N/m^2).

Table 1: Fluid properties

Density of water, ρ_w at 25°C	1000 kg/m^3
Density of diesel oil, ρ_o at 25°C	832 kg/m^3
Viscosity of water, μ_w at 25°C	8.9×10^{-4} Ns/m^2
Viscosity of oil, μ_o at 25°C	1.664×10^{-3} Ns/m^2

3.0 Results and Discussion

Only average values of the pressure drop obtained from three measurements were used in the calculation of percentage drag reduction as well as the viscosity readings. The DR calculated using Equation (1) was presented graphically against oil input volume fraction and pipe diameter (Figures 2 to 8).

3.1 Effect of oil input volume fraction, superficial velocity and pipe diameter

The DR of three polymers (HPAM, PEO and AVM) was studied in oil-water flow (Multiphase flow; MPF) at different oil input volume fractions (δ_o; 0, 0.25, 0.50, 0.75 and 1), superficial velocities (0, 1.17, 2.33, 3.50 and 4.67 m/s) and pipe diameters (0.012 and 0.02 m ID). Figures 2 - 4 show that, DR decreased with increase in the oil volume fraction (25 - 75%) due to decrease in the superficial velocity of the water phase because the DRP used were only soluble in the water phase. The decreased in superficial velocity of the water phase decreased the turbulent intensity of the water phase, this results to a decrease in DRP - turbulent eddies interaction and increase the pressure drop. The pressure drop increase (DR decreased) since the superficial velocity of the water phase inside the pipe was not enough to stretch the polymer molecules due to the increase in superficial velocity of the oil phase. This was in agreement with previous reports (Virk, 1975; Yusuf et al., 2013; Abubakar et al., 2014b; Abubakar et al., 2015b; Edomwonyi-Otu et al., 2015).

In addition, it was observed that at the same conditions, DR increased (58% to 62%; 62% to 65% and 43% to 54% for HPAM, PEO and AVM respectively) with decrease in the pipe diameter (0.02 – 0.012 m IDs). The velocity inside the pipe increased as the pipe diameter was reduced, resulting to a high pressure drop in the smaller pipe diameter, which increased in the degree of turbulence. The high degree of turbulence in the smaller pipe brings about formation of many smaller eddies in the water phase due to collisions of larger eddied. The DRP easily overcome smaller eddies due to lower amount of energy require by the smaller eddies than the larger once. This corroborate with the findings of Virk, (1975); Interthal and Wilski, (1985); Ahmad et al., (2009); Karami and Mowla, (2012). At lower flow rate, the effect of pipe diameter is clearly

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noticeable than at higher flow rate where DR values for 0.012 and 0.02 m are closed to each other.

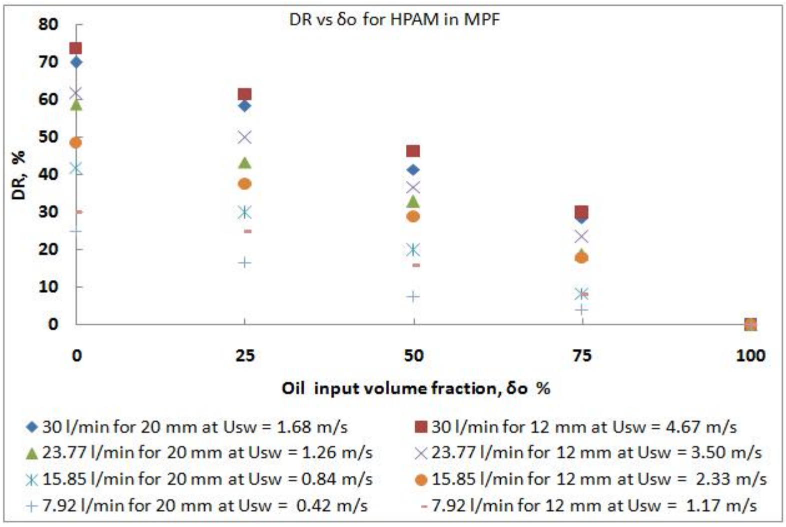

Figure 2: Effect of oil input volume fraction on drag reduction at different flow rate and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for HPAM.

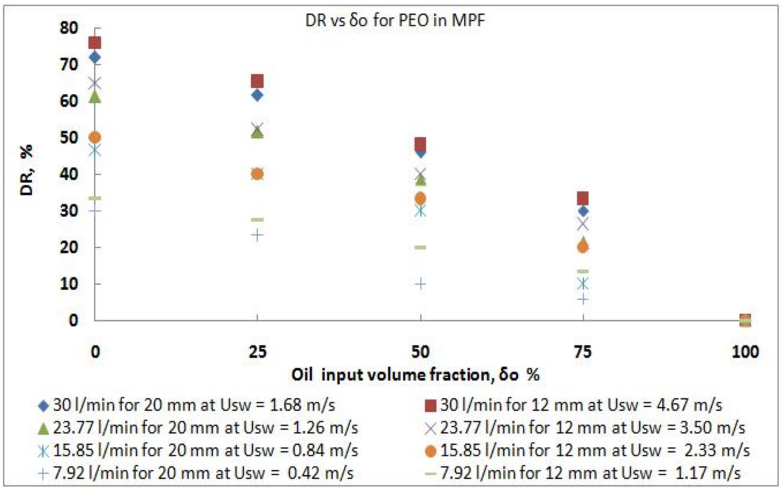

Figure 3: Effect of oil input volume fraction on drag reduction at different flow rate and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for PEO.

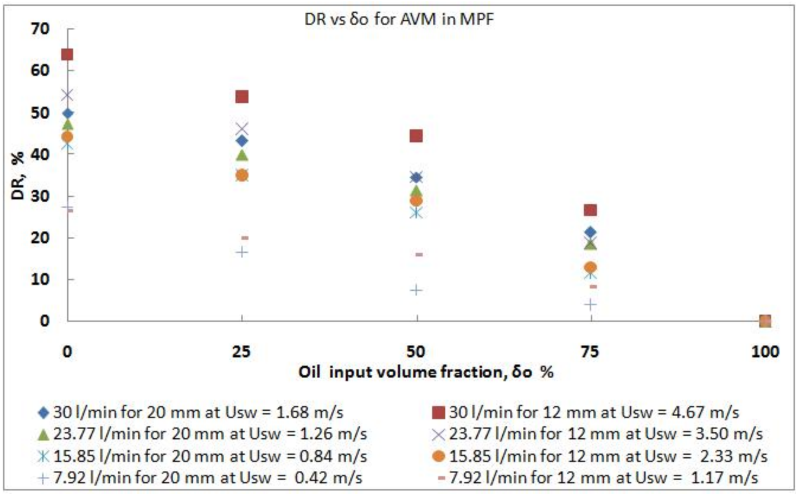

Figure 4: Effect of oil input volume fraction on drag reduction at different flow rate and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for AVM.

3.2 Effect of oil input volume fraction, superficial velocity and pipe diameter

The percentage DR of two polymer mixtures (HPAM-AVM and PEO-AVM) was studied in oil-water flow at different oil input volume fractions (0, 0.25, 0.50, 0.75 and 1), superficial velocities (0, 1.17, 2.33, 3.50 and 4.67 m/s) and pipe diameters (0.012 and 0.02 m ID). Figures 5 - 8 show that, DR decreased with increase in the pipe diameter (from 0.02 – 0.012 m IDs) at same conditions. Even though DR decreased due to the increase in oil input volume fraction, the effect of pipe diameter is clearly noticeable at lower flow rate than at higher flow rate. This corroborate with the previous findings (Virk, 1975; Interthal and Wilski, 1985; Ahmad et al., 2009; Karami and Mowla, 2012). Synergism in DR observed for both pipe diameters (0.012 and 0.02 m ID) in the water phase may be due to the interaction among the polymer molecules, which influence the extension of the molecules. It may also be attributed to the increase in the polymer coil dimension and their rigidity. This was in agreement with the work of Edomwonyi-Otu et al. (2016); Dingilian and Ruckenstein (1974); Reddy and Singh (1985); Malhotra et al., (1988); Gustavo and Soares (2016) who reported a decrease in drag reduction with increased pipe diameter.

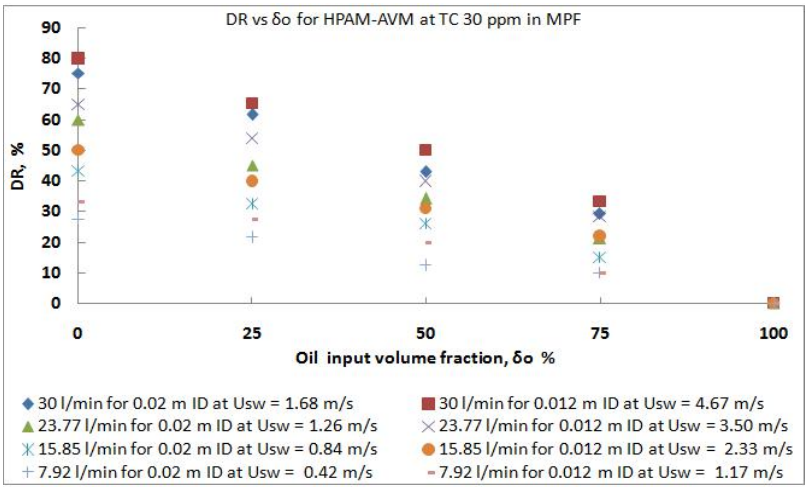

Figure 5: DR against oil input volume fraction at different flow rate (superficial velocity) and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for HPAM-AVM at total concentration of 30 ppm.

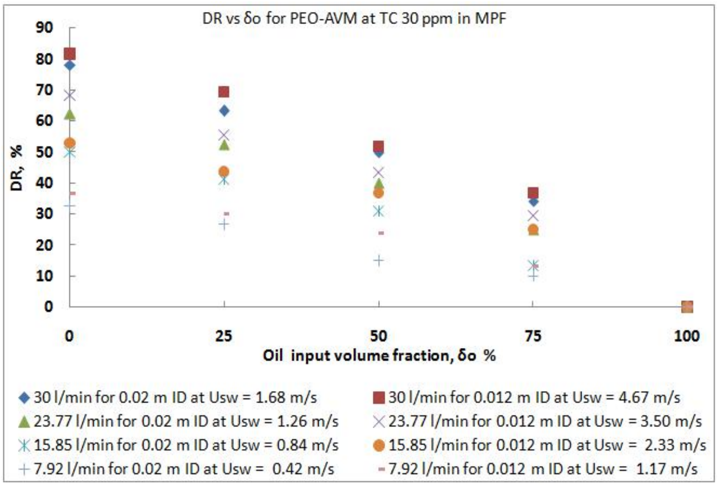

Figure 6: DR against oil input volume fraction at different flow rate (superficial velocity) and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for PEO-AVM at total concentration of 30 ppm.

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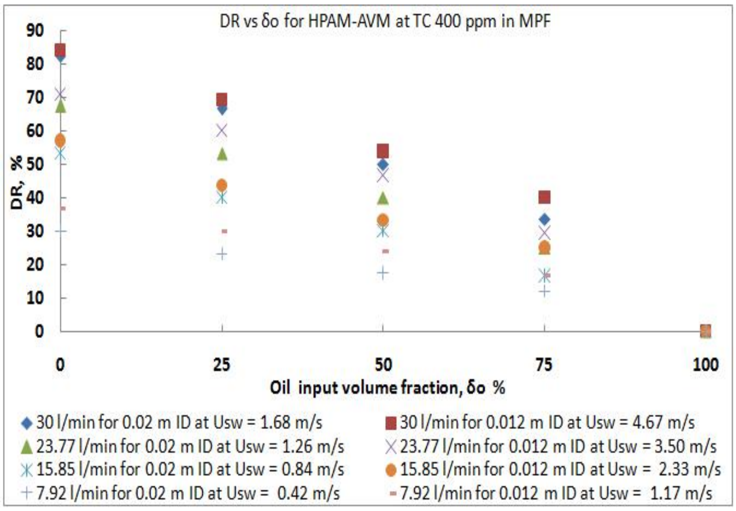

Figure 7:DR against oil input volume fraction at different flow rate (superficial velocity) and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for HPAM-AVM at total concentration of 400 ppm.

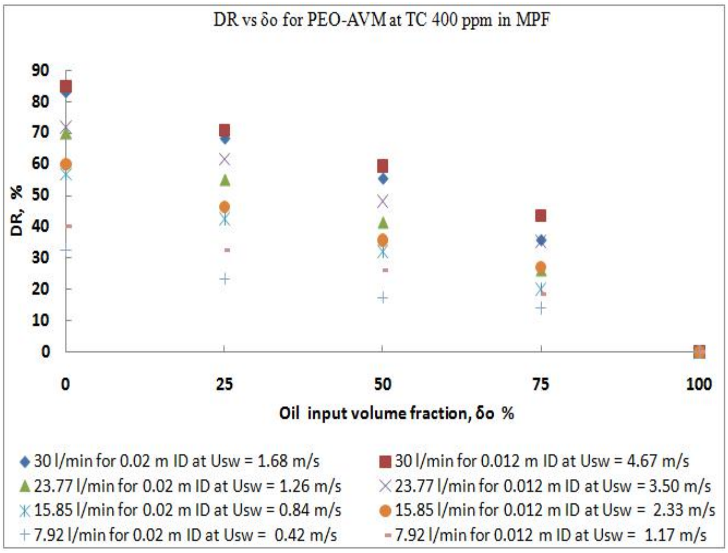

Figure 8: DR against oil input volume fraction at different flow rate (superficial velocity) and pipe diameter (0.012 and 0.02 m ID) in oil-water flow for PEO-AVM at total concentration of 400 ppm.

4.0 Conclusion

The effect of pipe diameter, oil input volume fraction and superficial velocity on drag reduction in oil-water flow has been studied. From the results obtained, it can be concluded that:

- DR decreased with an increase in pipe diameter and decrease in the superficial velocity of the water phase.
- DR is a function of oil input volume fraction, superficial velocity and pipe diameter.
- Combining HPAM and PEO onto AVM enhanced effectiveness of drag reduction of the AVM.

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