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Investigating the Effectiveness of Aloe Vera Mucilage in Drag Reduction

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Abstract

Drag reduction is the deliberate reduction of the frictional pressure drop experienced in flow systems by the addition of heavy molecular weight polymeric materials as well as other means such as pipeline modifications. The need for environmental friendly and cheaper heavy molecular weight polymeric drag reducing agents (DRAs) has become a necessity in the transportation of fluids particularly in the oil and gas industry. However, very few reports exist on the potentials of natural polymers such as extracts from the Aloe Vera plant. In this study, the effects of Reynolds number (mixture velocity) and polymer concentration on the drag reduction effectiveness of Aloe Vera mucilage were tested. An experimental flow facility of uPVC pipe of 20 mm ID was constructed using oil [diesel] (density = 832 kg/m^3, dynamic viscosity = 1.664 mPa.s at 25^{o}C) and water (density = 1000 kg/m^3, dynamic viscosity = 0.891 mPa.s at 25^{o}C) as test fluids. Concentration range of 50 ppm to 500 ppm and Reynolds numbers less than 60000 were investigated while pressure drop readings were measured using a U-tube manometer. These pressure variations were used to show the effectiveness of the Aloe Vera mucilage as a DRA. In single phase water flow, a maximum drag reduction of 50% (U = 1.683 m/s) was achieved in horizontal pipeline flow. Maximum drag reduction of 42.86% (α = 25%, Umix = 1.683 m/s) was observed in multiphase flow. Pipe inclination had minimal effect on the drag reduction. It was deduced that Aloe Vera mucilage can be used as a drag reducing agent in oil-water flows. However, it is recommended that the synergistic effect of the mucilage be further studied, as it is indeed a viable bio-degradable alternative to synthetic polymers.

Keywords: Drag Reduction, Natural DRAs, Aloe Vera, Oil-Water Flows

1. Introduction

Fluids are known to be transported through long stretches of pipeline in the process industry. It is well established that drag between the fluids and pipe wall causes substantial pressure drops along the pipelines (Al-Wahaibi et. al., 2007; Edomwonyi-Otu, 2015). Today, pumping systems constitute 20% of the world's electrical energy demand and they consume 20-50% of the energy usage in certain industrial plant operations (Hameed, 2014). There is a need to reduce the drag associated with the flow. Drag reduction refers to a process where the frictional pressure drop within a piping system is reduced deliberately (Manfield et. al., 1999; Edomwonyi-Out et.al., 2015). The relevance for practical applications is thus enormous. Savins, (1964) was the first in using the term "Drag Reduction" with the definition:

$$DR = \left[1 - \frac{\Delta P_{polymer}}{\Delta P_{solvent}}\right] x100$$

(1)

Where $\Delta P_{polymer}$ and $\Delta P_{solvent}$ signify the pressure drops in friction in the presence and absence of drag reduction respectively.

The key objective is to reduce the amount of energy required to carry out the pumping of the fluids through the pipes via several methods including the use of drag reducing agents. These drag reducing agents can be categorized as: polymers, surfactants, fibers, micro-bubbles and compliant coating. They have found wide applications such as in firefighting, wastewater treatment, irrigation control, district heating and cooling systems, and crude oil transport amongst others (Edomwonyi-Otu and Angeli, 2014). Their use in transportation of drinking water has been suggested because of their harmless nature and huge potential in reducing the cost of local water treatment and transport (Edomwonyi-Otu and Adelakun, 2018). This research however, focuses on the use of polymers as drag reducing agents; of particular interest is drag reduction in oil-water flows.

The first documented work on oil-water flows was carried out by Al-Wahaibi et al., (2007). They reported the effects of 20 and 50 ppm of Magnafloc 1011 (a co-polymer of polyacrylamide and sodium acrylate) injected into oil-water flows in a horizontal pipe on the pressure drops and flow patterns. The investigation was performed in 14-mm ID acrylic pipe. They reported a maximum drag reduction of 50%.

Al-Yaari et. al., (2009) injected 3 different molecular weight samples of 10-15 ppm polyethylene oxide into a 10 m long acrylic, horizontal 25.4 mm ID pipe. They discovered that pressure drop reduction was significant and it depended on water fraction, mixture velocity, concentration and molecular weight of the DRPs.

New research suggests that mucilage, a viscous substance found in plants, exhibits drag-reducing properties. Abdulbari et. al., (2011) used a 25.4 mm ID pipe and reported 63% drag reduction using Aloe Vera mucilage, in single phase water flow. Mucilage indeed fulfills the criteria of current demand as it has a natural and easily available source, and it is also biologically degradable.

Yusuf et al., (2012) also investigated the effect of a drag reducing polymer on pressure drops using a mineral oil in a 25.4 mm ID, 8 m long acrylic pipe. They noted that drag reduction increased with the polymer concentrations.

Abubakar, (2016) worked with an anionic copolymer of polyacrylamide and 2-Acrylamido-2-Methylpropane Sulfonic acid in a 30.6 mm pipe ID, using an inclined pipe orientation. He reported 64% drag reduction for horizontal oil-water flows. Positive inclinations led to slightly improved drag reduction, while negative inclinations had mixed results.

Works on natural polymeric materials in oil-water flows are generally scanty and as such, there is a need to explore this area thoroughly as it offers a biodegradable alternative to the synthetic polymers currently being used. This research aims to determine the effectiveness of Aloe Vera mucilage in multiphase flow.

2. Experimental Set-Up

The experimental set-up was designed and fabricated at the Chemical Engineering Department of Ahmadu Bello University

Zaria. A schematic diagram of the experimental set-up is shown in Figure 1.

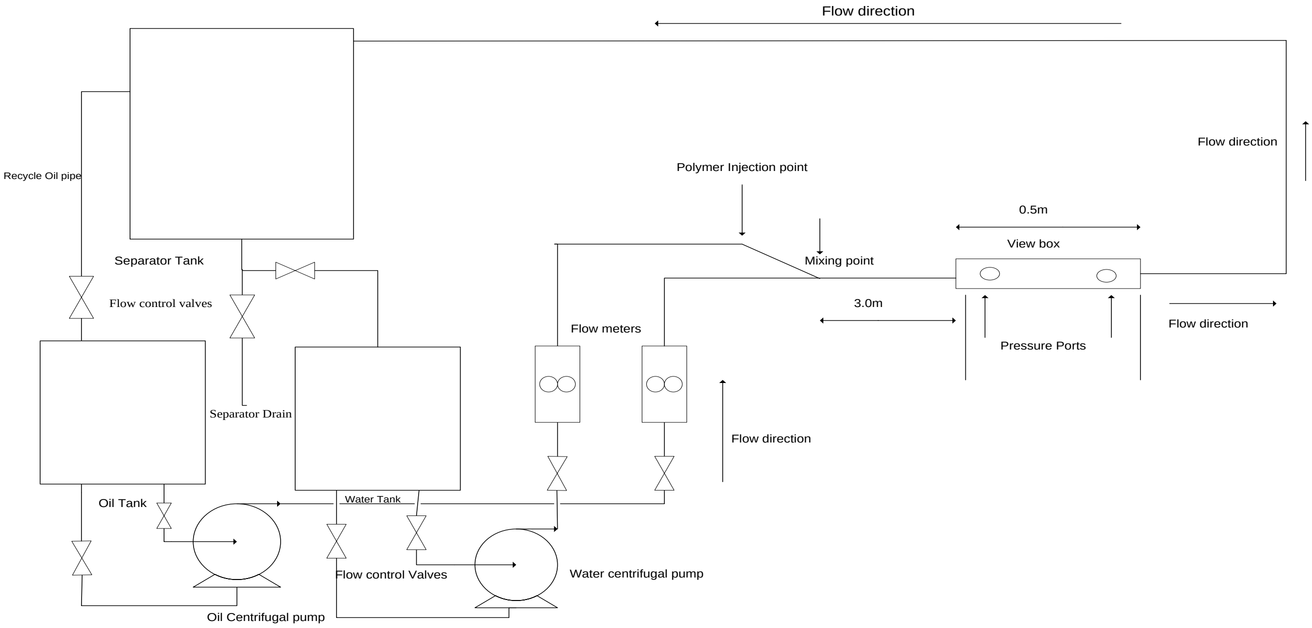

Figure 1: Schematics of experimental set-up

2.1 Polymer Preparation

Aloe Vera leaves were cut from the base of the plant and then washed thoroughly. These leaves were then cut vertically on both sides and soaked in water for 10 minutes, to remove the Aloin (bitter, yellow residue) within them. The leaves were then peeled and the Aloe Vera mucilage was extracted by scraping the gel from the aloe leaves and pressing on a sieve. Aloe Vera leaf contains 98% water (Davis, 2007) while the remaining 2% is the active Aloe Vera. 20,000 ppm master solution of the mucilage was prepared and used immediately after preparation. The master solution was then injected into the water phase at specific flow rate and at a distance of 0.5 m before the Y-junction in order to achieved the require concentration in the water flow line. A polymer injector pump (New Era Model No. NE-9000; ±2%) was used for the polymer injection in the test section. It has a minimal effect on the fluid; hence the polymer solution was not subjected to mechanical degradation during injection into the test section. A material balance was used to achieve the required concentration in the water phase.

2.2 Experimental System

The experimental system consisted of two buildup tanks (for water and diesel respectively), with capacity of 200 liters each; Two 1 horsepower centrifugal pumps (Jet 102M/N.31227); 0.02 m ID unplasticized polyvinylchloride (uPVC) pipes; U-tube manometer; Globe valves and two flowmeters (LZM-20J; accuracy ±5%). The U-tube manometer (Pyrex) was used to measure the pressure drop. The two flowmeters were used to regulate the flow rate of fluid.

From each of the storage tanks, a centrifugal pump was used to transport the fluid to the testing section. Each flow line was fitted with a flow meter and a globe valve. The flow meters were calibrated before use. The fluids were brought together via the use of a smooth Y-junction (at an angle of 45^o), which minimized their mixing (Edomwonyi-Otu et al., 2014; 2015). The design is such that the diesel enters from the top and the water from the bottom before reaching the testing area. The drag reducing agent was injected using a New-Era programmable peristaltic pump (model NE-9000; ±2%) before the point of mixing, into the water phase.

The test section comprised of 0.02 m ID uPVC pipe, a 1m long acrylic view section with two pressure ports located 0.5 m apart and a U-tube manometer connected via rubber tubing to the pressure ports. The first pressure port was located 3.0 m from the mixing point; well in excess of the required 50D, to allow for fully developed turbulent flow before pressure drop readings were taken. Aloe Vera mucilage concentrations, ranging from 50 ppm to 500 ppm were used and Reynolds numbers <60,000 were investigated for the single phase experiments. While a mixture velocity (Umix) range of 1.68 to 0.4 m/s was used for the multiphase flow experiments. With oil input fraction ranging from 0 to 1. The concentration and flowrate at which the optimum DR was achieved in single phase was used and confirmed by using concentrations slightly above and below the optimal value in the multiphase experiments. Then, the velocity at that particular flowrate was taking as the mixture velocity (Umix) of the test fluids.

The separator, with a capacity of 220 liters, was used to recovered used diesel which was then recycled back to the diesel buildup tank. This separation was done using the differences in density between the testing fluids. Drag reductions were determined for both single and multiphase experiments using equation 1.

The experiments were carried out for horizontal flow, 2^0, -2^0 and -5^0 inclinations and the results were then compared.

3. Results and Discussion

3.1 Single Water Phase Drag Reduction

Figure 2 shows drag reductions against Reynolds number at different polymer concentrations. It can be observed that as Reynolds number increases the drag reduction also increases. This is because the increasing Reynolds number leads to an increase in turbulence in the system (Edomwunyi-Otu,2015). This may have then resulted in the polymer molecules stretching further. As they stretch, they further absorb the energy within the system; leading to the suppression of turbulence and as a result, the drag is reduced.

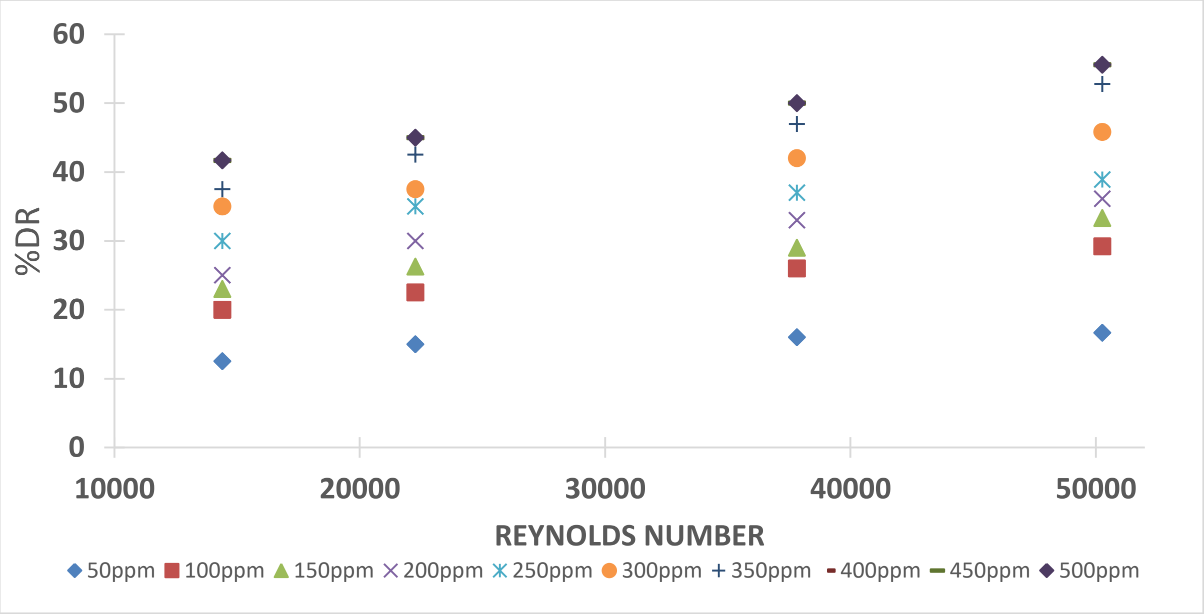

Figure 2: Effect of Reynolds number on percentage drag reduction of the various tested DRA concentrations

This phenomenon continues until a plateau level is reached. As observed at 400 ppm in Figure 2, further increase in the polymer concentration did not yield a corresponding increase in drag reduction. Addition of 450 ppm and 500 ppm of the Aloe Vera mucilage result in the same drag reduction as that observed at 400 ppm. It can be deduced that 400 ppm is the optimal concentration of the system. This may have occurred as a result of the system becoming saturated with DRA molecules to the point where further addition had very little effect on drag reduction. In fact, it could lead to increase in the overall viscosity of the system.

These findings are in agreement with results obtained from Al-Wahaibi et al., (2013) and Abubakar, (2016). Although they both used synthetic polymers, they also observed a steady increase in drag reduction with increased Reynolds number until a plateau point was reached. The maximum drag reduction observed was at 400 ppm, 450 ppm and 500 ppm (50% drag reduction).

In view of these findings, it is safe to suppose that further the increase in the concentration of the DRA beyond 400 ppm will not cause appreciable increase in drag reduction. These results add to the data already established in the field of drag reduction.

3.2 Multiphase Drag Reduction

The optimum polymer concentration in multiphase was confirmed to also be 400 ppm. Figure 3 to 5 present the drag reduction obtained in the multiphase experiments. It can be seen that drag reduction is most effective in the pure water phase (α = 0). And subsequently as the diesel is added, the percentage drag reduction reduces continuously until it is 0 in the pure diesel phase (α = 1). Essentially as the superficial velocity of water (Usw) decreases, the water Reynolds number also reduces thus reducing the effectiveness of the drag reduction.

This is in agreement with the findings of Edomwonyi-Otu, (2015) and Abubakar, (2016). They noted that addition of a water-soluble DRA in oil-water flows resulted in drag reduction being inversely proportional to the oil input fraction. It can thus be deduced that drag reduction only takes place in the water phase. In addition, there were very little to no changes in drag reduction at mixture velocities lower than 0.4 m/s by the addition of the DRA. This could be due to the fact that DRA was only effective on the flow in the turbulent region. Since it only acted in the water phase and at this low mixture velocity, the water phase is either in laminar or transitional flow region.

Also, it is observed that the optimal concentration of the DRA was the same as in the single phase, as the maximum drag reduction observed was also at a DRA concentration of 400 ppm.

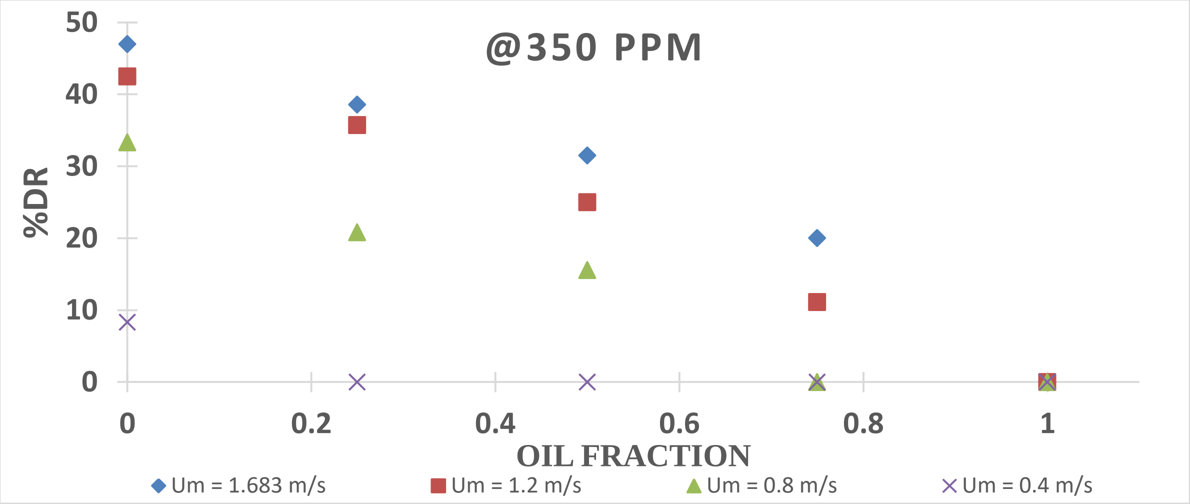

Figure 3: Effect of oil fractions on drag reduction at various mixture velocities (at concentration of 350 ppm)

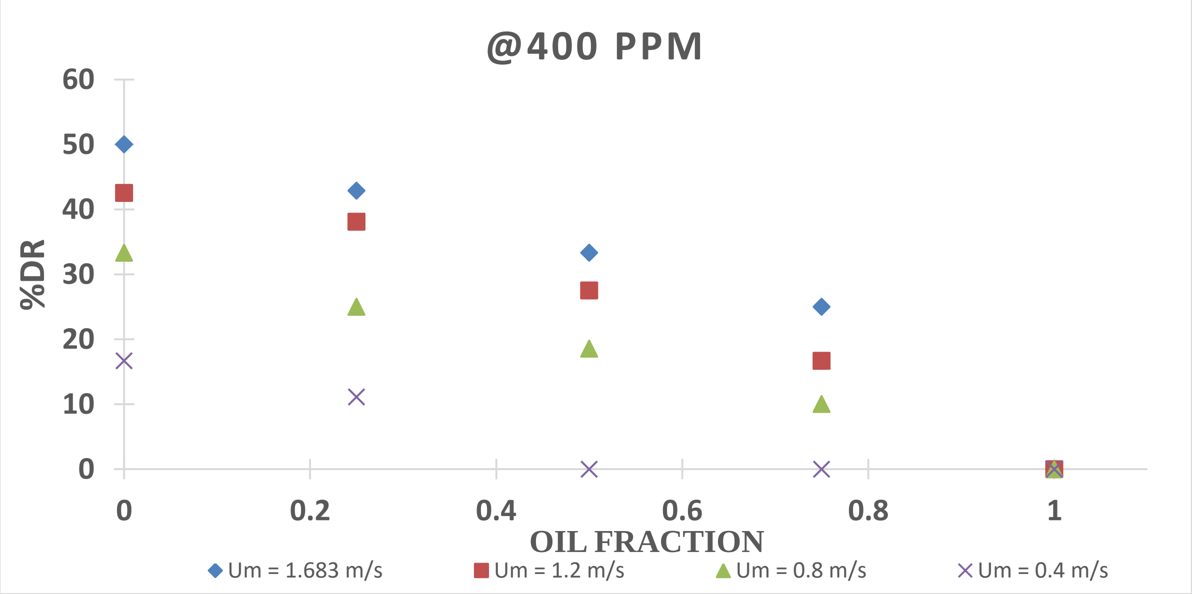

Figure 4: Effect of oil fractions on drag reduction at various mixture velocities (at concentration of 400 ppm)

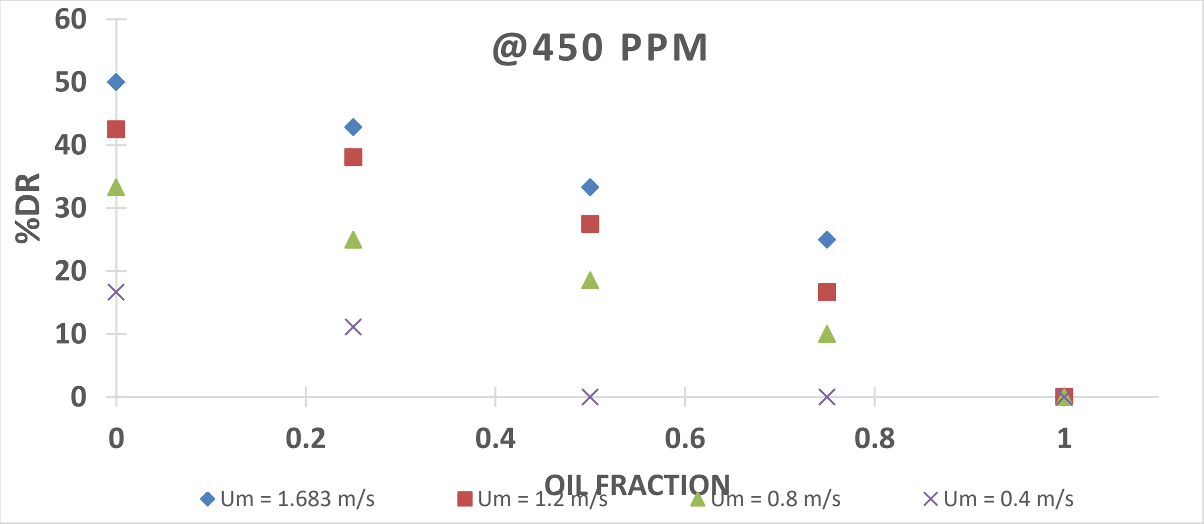

Figure 5: Effect of oil fractions on drag reduction at various mixture velocities (at concentration of 450 ppm)

3.3 Effect of Inclination

Naturally, it is expected that the introduction of inclination will affect the total pressure drop of the system as the gravitational pressure drop is affected either positively or negatively. As observed by Abubakar, (2016) the new additional gravitational force creates both normal and parallel pressure gradient components to the pipe axis. The optimum DRA concentration obtained in earlier experiments was also used here.

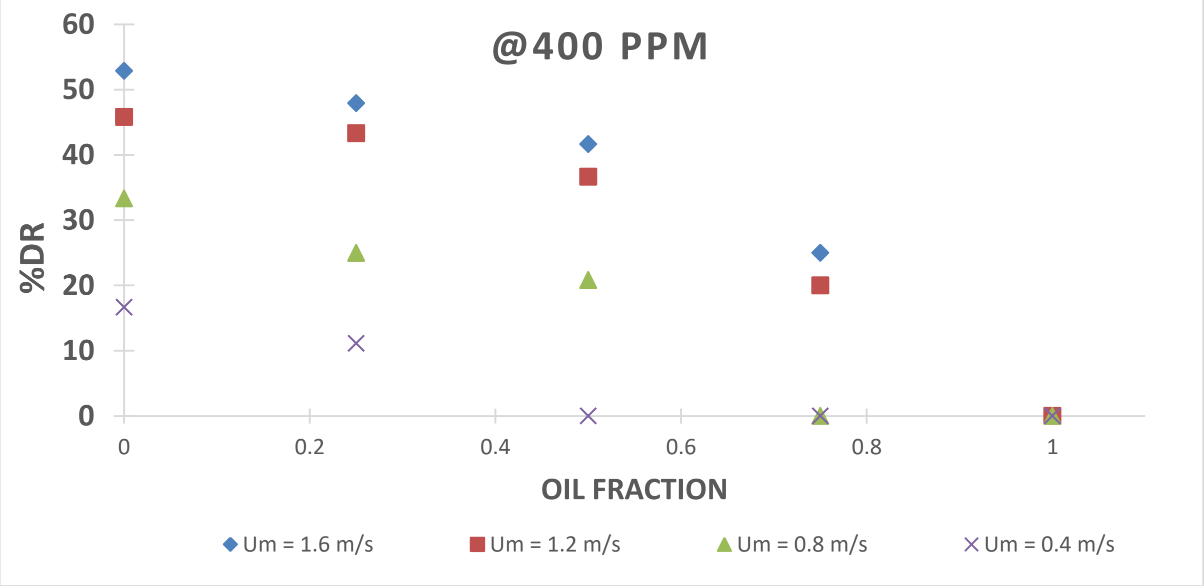

Figure 6: Effect of oil fractions on drag reduction at various mixture velocities (2^0 inclination)

The drag reduction increased with increase in the mixture velocity but with decrease in the oil volume fraction, reaching a maximum drag reduction of about 52.82 % (α = 0) and 47.92 % at flow condition of 1.683 m/s mixture velocity and 0.25 input oil volume fraction.

These results showed slightly increased drag reduction compared to the results obtained in the horizontal pipe orientation. Lum et al. (2006) observed that the added gravitational component leads to increased mixing between the phases. This in turn leads to dispersion of oil in the water phase. These complex interactions change the dynamics within the system and may reduce the amount of oil in contact with the pipe walls and as such reducing the total pressure of the system, thus improving drag reduction.

These findings are in line with observations made by Abubakar, (2016), who reported higher drag reduction at 5^0 inclination in a 30.6 mm pipe ID, when compared to horizontal flow.

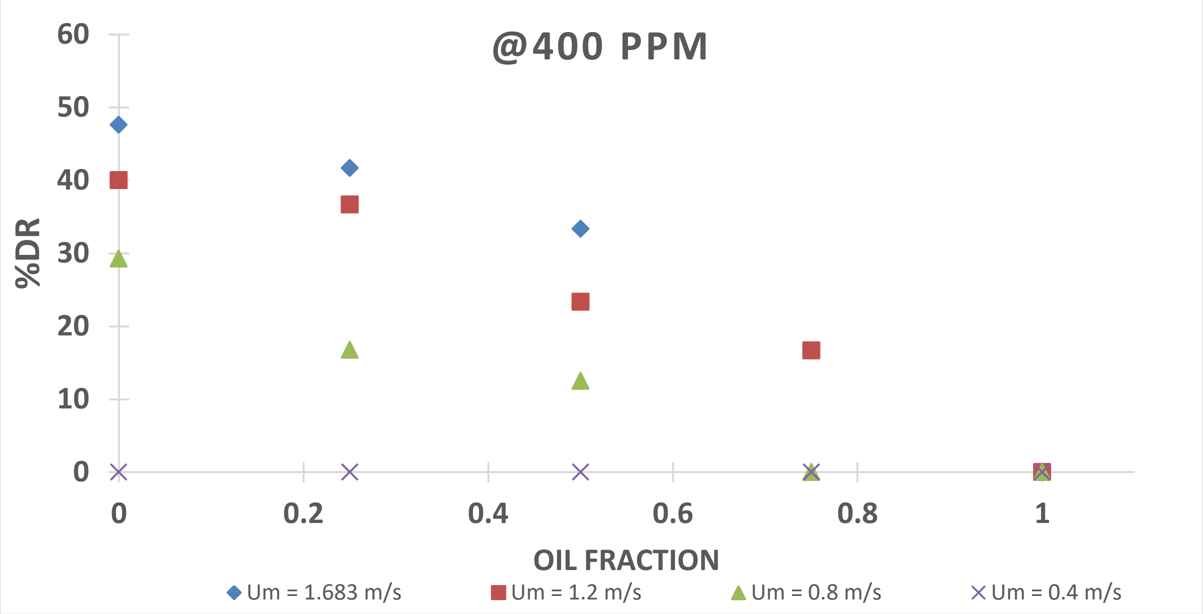

Figure 7: Effect of oil fractions on drag reduction at various mixture velocities (-2^0 inclination)

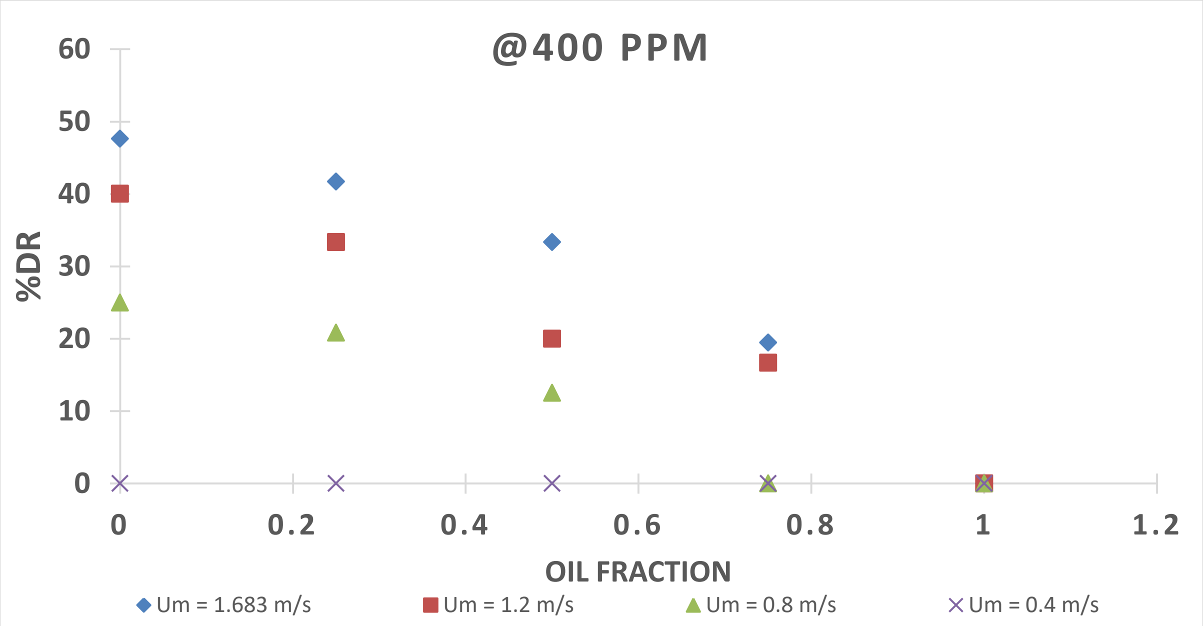

Figure 8: Effect of oil fractions on drag reduction at various mixture velocities (-5^0 inclination)

Figures 7 and 8 show the drag reduction with respect to input oil volume fractions and mixture velocities for -2^0 and -5^o inclinations respectively. Generally, the drag reduction increased with increase in mixture velocity but decreased with increase in input oil volume fraction. Both negative inclinations produced slightly lower drag reductions. It should also be noted that these findings are similar to the previous results obtained for horizontal and inclined flow in terms of the trend against the variable parameters.

The highest drag reduction observed for both -2^0 and -5^0 inclination was about 47.62 % (α = 0) and 41.67 % at flow condition of 1.683 m/s mixture velocity and 0.25 input oil volume fraction. Results obtained indicated slightly lower drag reduction than those observed for horizontal flow. As flow is aided by gravitational forces, there may be increased turbulence in the system and uneven mixing. This could lead to the DRA not uncoiling as effectively as in horizontal set-up and absorbing the energy of the flow. This could in turn slightly reduce the effectiveness of drag reduction. Also, the angle of inclination itself did not seem to significantly affect drag reduction.

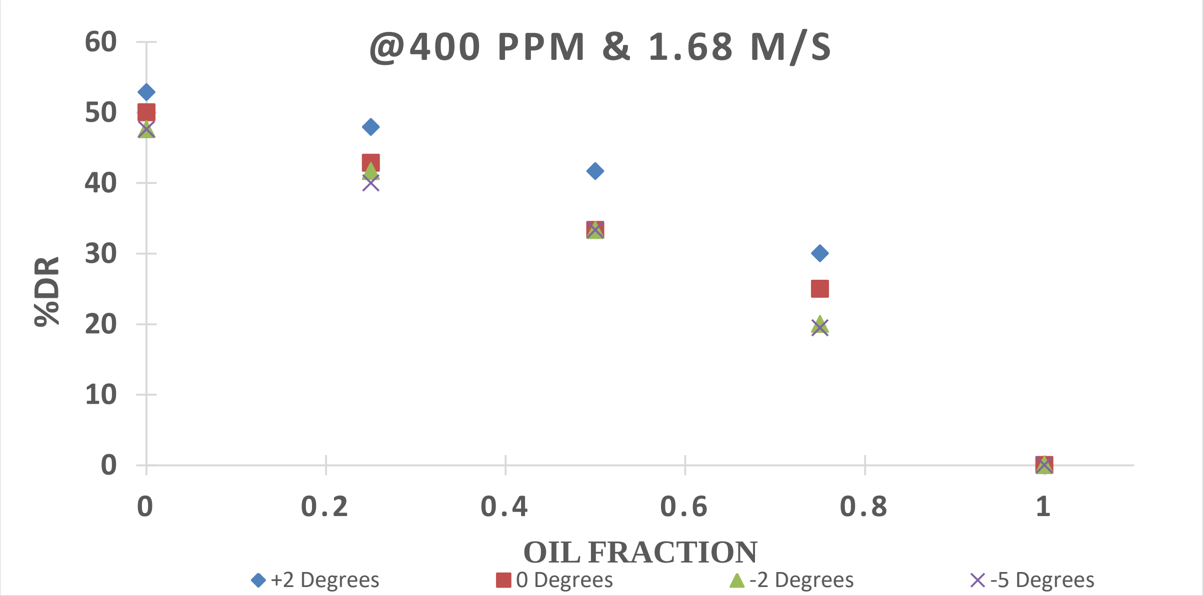

Figure 9: Effect of angle of inclination on drag reduction

As mentioned before, inclination slightly enhanced the drag reduction observed for horizontal flow. While, declination produced slightly lower drag reduction. These changes can be attributed to oil dispersion in the water phase and the addition of the gravitational pressure drop to the total pressure drop of the system, thereby affecting the observed drag reduction.

Conclusion

From all the experiments carried out and the results obtained, the following conclusions can be drawn:

- A maximum drag reduction of 50% was achieved using a 20 mm ID pipe in single phase water flow.

- Drag reduction increased as Reynolds number increased.
- Multiphase flow experiments showed that the addition of the DRA only affected the water-dominated flow regions.
- Drag reduction reduced as the oil fraction increased. Maximum drag reduction of 42.86% was achieved at an oil input fraction of 25%
- Pipe inclination and declination had minor impact on the effectiveness of drag reduction.
- Aloe Vera was determined to be a viable drag reducing agent in oil-water flows.

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