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ORIGINAL RESEARCH ARTICLE

ALOE VERA MUCILAGE AS DRAG REDUCING AGENT IN OIL-WATER FLOW

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ABSTRACT

Drag reduction is the deliberate reduction of the frictional pressure drop in flow systems by the addition of heavy molecular weight polymeric materials as well as other means such as pipeline modifications. Environmentally 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 and polymer concentration on the drag reduction effectiveness of Aloe barbadensis miller were tested. An experimental flow facility using unplasticized Polyvinylchloride (uPVC) pipe of 12 mm ID was constructed with diesel (density = 832 kg/m^3, dynamic viscosity = 1.664 mPa.s at 25°C) and water (density = 1000 kg/m^3, dynamic viscosity = 0.891 mPa.s at 25°C) as test fluids. Drag reduction as a function of Aloe polymer concentration in the range 50 ppm to 500 ppm and Reynolds number $20000<Re<90000$ were investigated by comparing the U-tube manometer pressure drop readings with and without aloe polymer. The pressure drop difference expressed as a percentage of the pressure drop without aloe polymer is termed drag reduction and was used to demonstrate the effectiveness of the Aloe Vera extracts or polymer as a DRA. In single phase horizontal (water) flow, a maximum drag reduction of 64% (U = 4.67 m/s) was measured, while in multiphase horizontal flow, a maximum drag reduction of 53.80% (α = 25%, U_m = 4.67 m/s) was measured. Furthermore, measurements showed that pipe inclination had minimal effect on the drag reduction achieved. It was deduced that Aloe Vera mucilage can be used as a drag reducing agent in oil-water flows for Reynolds number below 63,000.

1.0 Introduction

One of the major operations in the process industry is the transportation of fluids along pipelines. It has been shown that frictional drag between the fluids and pipe wall causes substantial pressure drop along the pipelines (Al-Wahaibi and Angeli, 2007; Edomwonyi-Otu, 2015). Today, pumping systems constitute 20% of the world's electrical energy demand and consumes 20-50% of the energy usage in certain industrial plant operations (Hameed, 2014). Hence, the importance of drag reduction cannot be overemphasized. Drag reduction generally refers to a process where the frictional pressure drop within a piping system is deliberately reduced thus significantly reducing pumping energy required (Manfield et al., 1999; Edomwonyi-Otu and Angeli, 2014; Edomwonyi-Otu, 2015). The relevance for practical applications is thus enormous (Edomwonyi-Otu and Adelakun, 2018). Savins (1964) was the first to use the term "Drag Reduction" with the definition:

$$\mathrm{DR} = \left[\frac{\Delta P_{\mathrm{solvent}} - \Delta P_{\mathrm{polymer}}}{\Delta P_{\mathrm{solvent}}}\right] \mathrm{X}100 \qquad (1)$$

where: ΔPpolymer and ΔPsolvent (N/m2) signify the frictional pressure drops in the presence and absence of drag reducing polymers respectively.

Drag reduction can be carried out via several methods including the use of drag reducing agents (Edomwonyi-Otu and Adelakun, 2018). Drag reducing agents are added to the flow in order to reduce frictional drag and can be categorized as: polymers, surfactants, fibers, micro-bubbles and compliant coating. This research however is limited to the use of natural polymers as drag reducing agents in oil-water flow. The first documented work on oil-water flow was carried out by Al-Wahaibi and Angeli, (2007). They investigated the effects of Magnafloc 1011 (a co-polymer of polyacrylamide and sodium acrylate) on the pressure drop and flow patterns of oil-water flows in a 14-mm ID horizontal acrylic pipe. They reported a maximum drag reduction of 50%. Yusuf et al., (2011) also investigated the effect of a DRP (Drag Reducing Polymer) on pressure drops using a mineral oil in a 25.4 mm ID. They noted that drag reduction showed an increase with the polymer concentrations. They reported a maximum drag reduction of 60% in oil-water flow.

Recently, Edomwonyi-Otu (2015), Edomwonyi-Otu et al. (2015), and Edomwonyi-Otu and Angeli (2019) investigated the effect of DRP on oil-water mixture in a horizontal 14-mm ID acrylic pipe. They used low concentration of solutions of partially hydrolysed polyacrylamide (HPAM, 8 x 106 g/mol.) and two types of PEO (5 x 106 and 8 x 106 g/mol.) and as drag reducing agents. The changes that occur to Reynolds stresses with polymer addition were studied with particle image velocimetry (PIV) technique. The addition of 20 ppm of HPAM resulted in DR of 80% in water flows as well as 52% in oil-water flows. In addition, the turbulence properties (velocity profiles and Reynolds stresses) as well as the interfacial wave characteristics of the flows were affected by the polymer addition. Higher molecular weight polymers gave better DR owing to their better ionic strength and resistance to mechanical degradation. Their reports supported the proposed mechanism of drag reduction that suggests that turbulent kinetic energy of flows is redistributed with addition of polymeric solutions.

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 inclination led to 3.3% improved drag reduction (when compared to horizontal flow), while negative inclinations had mixed results; varying between increased and decreased drag reduction when compared to horizontal flow. A general problem encountered in drag reduction studies is the fact that though many mechanisms of drag reduction have been brought forward (Al-Sarkhi, 2010; Manfield et al., 1999; Mowla and Naderi, 2006; White and Mungal, 2008), none have been universally accepted. Lumley (1973) postulated that the increased extensional viscosity due to the stretching of randomly coiled polymers tends to dampen the small eddies in the buffer layer and thickens the buffer layer, to give rise to the drag reduction. Conversely, De Gennes (1990), criticized the

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earlier extensional viscosity postulate. He went on to argue that the elastic energy stored in the macromolecules are responsible for drag-reduction.

Reports in some extant literature suggest that mucilage, a viscous substance found in plants, exhibits drag reducing properties. Lim, (2010) used extracts from Malabar Spinach in a 25.4 mm pipe ID and achieved 78.2% drag reduction in single water flow. Abdulbari (2011) studied the effects of Aloe Vera mucilage in single phase flow and achieved a maximum drag reduction of 63% in a 25.4 mm pipe ID. However, reports studies using natural polymers in oil-water flows are generally unavailable There is therefore a need to explore this system in order to generate more data on drag reduction using natural polymers in oil-water flows. This will give insight on the extent of drag reduction that can be achieved using natural polymers in oil-water flows. Hence, this research aims to determine the effectiveness of Aloe Vera mucilage, a natural polymer, in oil-water flow.

Natural DRAs also offer a biodegradable alternative to the synthetic polymers currently being used. This study aims at determining the effectiveness of Aloe Vera mucilage as a drag reducing agent in multiphase flow.

2. Experimental Set-Up

The experimental set-up was designed and fabricated at the Chemical Engineering Department of the Ahmadu Bello University Zaria, Nigeria. A schematic diagram of the experimental set-up is shown in Figure 1.

2.1 Polymer Preparation

Aloe Vera leaves were cut from the base of the plant and washed thoroughly. The 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 No. 4 (4.75 mm) sieve. Aloe Vera leaf contains 98% water Davis, (1997) while the remaining 2% is the active Aloe Vera. This was carried out in the chemical engineering laboratory of the Ahmadu Bello University, Zaria, Nigeria. The 20,000 ppm master solution was then used immediately after preparation. A polymer injector pump (New Era Model No. NE-9000; ±2%) was used to introduce the polymer solution into the test section. A material balance was used to achieve the required concentration in the water phase.

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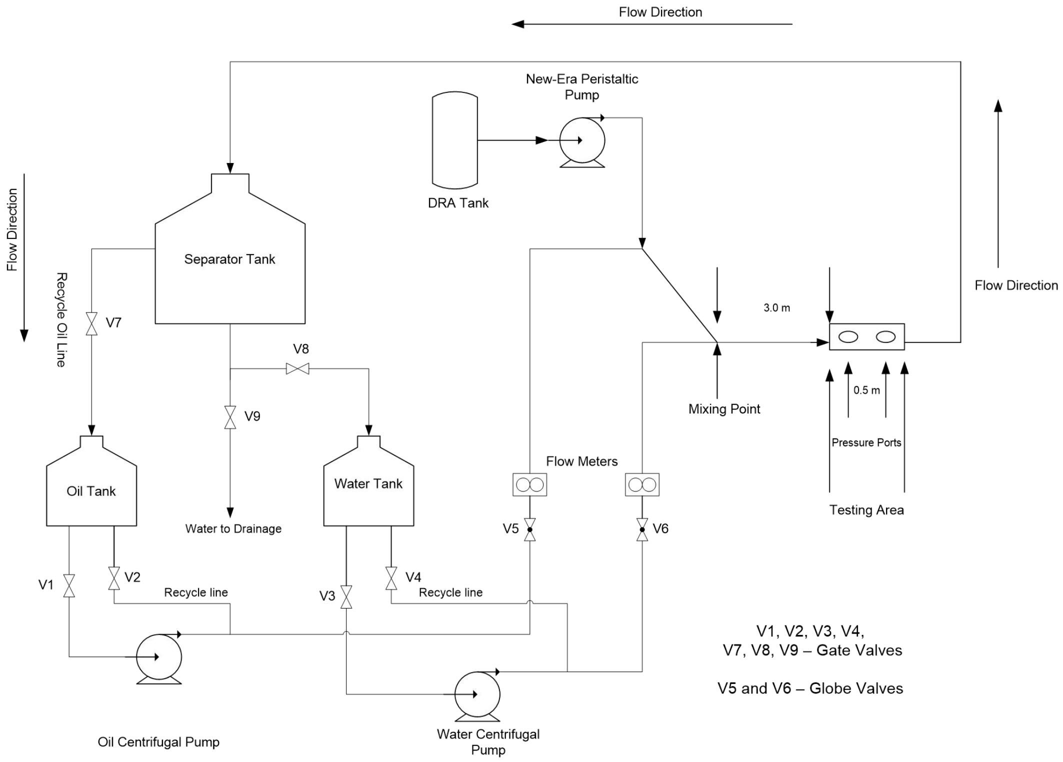

Figure 1: Schematic representation of the experimental flow facility for drag reduction

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 surface pumps. 0.012 m ID unplasticized polyvinylchloride (uPVC) pipes. A U-tube manometer. Globe and Gate valves and two (LZM-20J; ±5%) flowmeters, with capacities of 60 L/min. The U-tube manometer (Pyrex) was used to detect the pressure drop and the flow meters, used to regulate the flow rate of fluid passing through pipes.

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 gate valve. The flow meters, with two globe valves attached for regulation, were calibrated before use. The fluids were brought together via the use of a smooth Y-junction (at an angle of 45°), which minimized their mixing. The design was such that the diesel entered from the top and the water from the bottom before reaching the testing area. The prepared 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 0.012 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 recommended 150 times the diameter of the pipe used (Lien et al., 2004). This is 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. Also, several Reynolds numbers were used (by varying the input flowrate), with a maximum Reynolds number of 83,690.20 investigated for the single-phase experiments. For the multiphase experiments, oil (diesel) was introduced to the system at different concentrations. A mixture velocity (Umix) range of 4.67 to

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1.11 m/s was used and oil input fraction ranged from 0 to 1. In the single-phase experiments, an optimal concentration of the DRA was observed and recorded (the point at which further addition of the DRA did not yield an increase in the observed drag reduction). The concentrations and flowrate at which the optimum drag reduction was achieved in single phase was adopted for the multiphase experiments. DRA concentrations higher and lower than the optimal, were used to confirm if the drag reduction would change, thus changing the optimal concentration for multiphase flow. The drag reduction in both cases showed no change, thereby confirming the optimum DRA concentration in single-phase and multiphase to be the same. The optimal flowrate from the single-phase was also used to determine the optimal velocity. This was then used to determine the mixture velocity for the oil and water in the multiphase experiments.

The separator, with a capacity of 220 liters, was used to recover used diesel; which was then recycled to the diesel buildup tank. This separation was done using the differences in density between the testing fluids (Helmenstein, 2017). Drag reductions were determined for both single and multiphase experiments using Equation 1. The experiments were carried out for horizontal flow, 2° inclination and also -2° and -5° inclinations (2° and 5° declinations). The results were then compared.

3. Results and Discussion

3.1 Single Water Phase Drag Reduction

Figure 2 shows percentage drag reductions against polymer concentration at different Reynolds number (NRE). It was observed that drag reduction increases as the polymer concentration is increased. This may be as a result of the increased amount of polymer particles available to interact in the system. These particles suppress eddies and further thicken the buffer layer (Lumley, 1969). This phenomenon continues until a plateau point is reached. As observed at 400 ppm, further increase in the polymer concentration did not yield a corresponding increase in drag reduction. Injection of 450 ppm and 500 ppm resulted in the same drag reduction as observed at 400 ppm. This occurrence may be as a result of the turbulent structures of the flow becoming saturated with DRA molecules (Edomwonyi-Otu, 2015) to the point where further addition had very little effect on drag reduction; as the overall viscosity of the system is increased (Hameed et al., 2014). It can thus be deduced that, for this system, 400 ppm of Aloe Vera mucilage is the critical concentration.

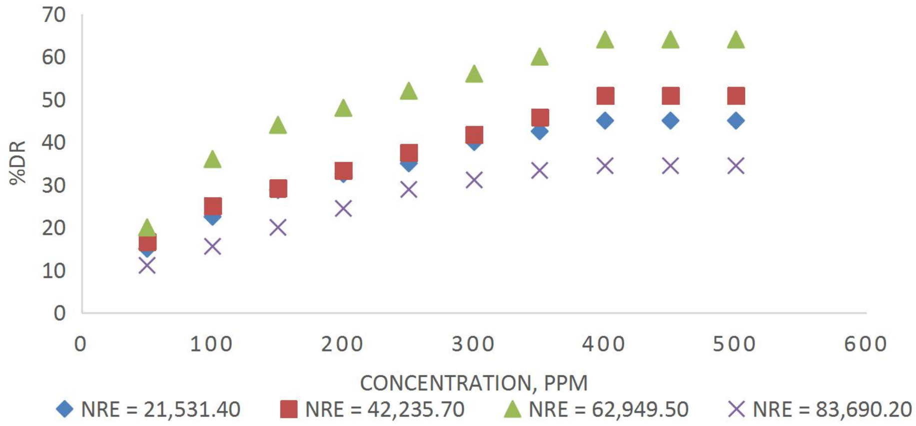

Figure 2: Effect of polymer concentration on percentage drag reduction at various Reynolds numbers.

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It can also be observed in Figure 2 that as Reynolds number increased, the drag reduction also increased, until a threshold Reynolds number was reached at 62,949. After which (at Re=83,690) drag reduction dropped significantly. This may be attributed to the increased Reynolds number and subsequently, increased turbulence in the system; resulting in the polymer molecules stretching further. As they stretch, they further absorb the energy within the system. This leads to the suppression of turbulence and as a result, drag is reduced. The findings are in agreement with results obtained from Yusuf et al., (2011) 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 for this system was at 400 ppm, 450 ppm and 500 ppm.

However, beyond a Reynolds number of 62,949, it can be deduced from the increase in drag (decrease in drag reduction) that the Aloe Vera mucilage undergoes mechanical degradation due to the very high velocity within the system. As such, the DRA becomes much less effective beyond this point. It has been reported that his mechanical degradation is one of the drawbacks of natural polymers in drag reduction (Kamarulizan, 2012). For comparison, Abubakar, (2016) used a synthetic copolymer of polyacrylamide and 2-Acrylamido-2-Methylpropane Sulfonic acid and did not experience degradation of the DRA at Reynolds number as high as 120,000.

In view of these findings from the preliminary investigation, it is safe to suppose that further increase in the concentration of the DRA beyond 400 ppm would not cause appreciable increase in drag reduction. The single phase experiments also confirmed the use of Aloe Vera mucilage as a drag reducing agent in single phase (water) flow, as established by (Abdulbari et al., 2011). Different operating conditions were selected to improve data on the viability of the natural DRA and it proved to be as effective as in their work.

3.2 Drag Reduction in Multiphase Flow

An optimum concentration of 400 ppm was used, as obtained from the single phase experiments. Figure 3 represents the drag reduction obtained in the multiphase experiments. The algebraic summation of the superficial velocity of water (Usw) and the superficial velocity of oil (Uso) gives us the mixture velocity used in the experiments. It can be seen that drag reduction is most effective in the pure water phase ($\alpha = 0$). Subsequent addition of diesel resulted in the percentage drag reduction reducing continuously until it is 0; in the pure diesel phase ($\alpha = 1$). Given that a water soluble DRA is used, it is expected that as the water Reynolds number decreased, the drag reduction observed will decrease. Essentially, as the superficial velocity of water (Usw) decreases, the water Reynolds number also reduces; thus reducing the effectiveness of the drag reduction. As established in the single phase experiments and previous works, drag reduction increases as Reynolds number increases and vice versa. 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 flow 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, since the aloe mucilage is insoluble in diesel oil and thus doesn't interact with it. A maximum drag reduction of 64% was therefore recorded at 0 oil fraction, 400 ppm and Um = 4.67 m/s.

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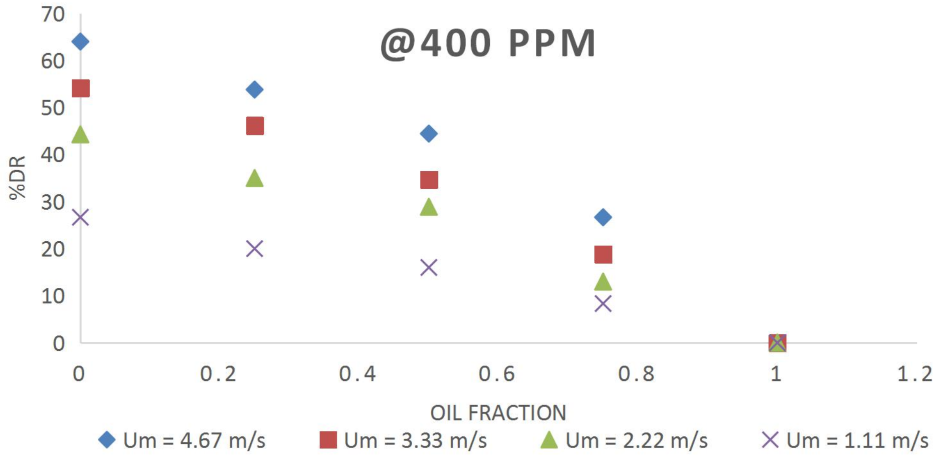

Figure 3: Effect of oil fractions on drag reduction at various mixture velocities (horizontal flow)

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. Indeed, Al-Sarkhi et al., (2006) established that an inclination of as little as 1.24o altered the effectiveness of drag reduction. As observed by Abubakar, (2016) the new additional gravitational force creates both normal and parallel pressure gradient components to the pipe axis. Figures 4 to 7 detail the effect of inclination on the system and the performance of the natural DRA used, under these conditions. The optimum DRA concentration of 400ppm obtained in earlier experiments was also used here.

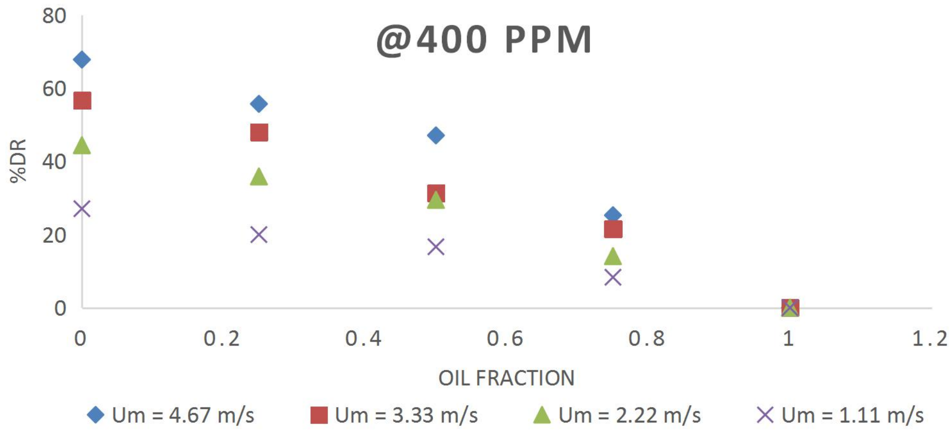

Figure 4: Effect of oil fractions on drag reduction at various mixture velocities and 20 inclination

Figure 4 shows the effect of a 2o inclination on the drag reduction. It is observed that similarly to the case of horizontal flow, drag reduction increases with increase in mixture velocity and decrease in oil fraction. However, there is a slight increase of about 4% in drag reduction in the 2o inclined flow compared to the horizontal flow for α = 0, Um = 4.67 m/s and 400 ppm aloe mucilage concentration. Consistently, other points on the 2o inclined flows showed slight increase in drag reduction over the horizontal flows.

Lum et al., (2006) observed that the added gravitational flow component leads to increased mixing between the phases. This in turn leads to dispersion of oil in the water phase thus reducing the amount of oil in contact with the pipe walls (drag-inducing flow reduces),

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consequently reducing the total pressure drop of the system, and thereby enhancing the effectiveness of drag reduction. These findings are in line with observations made by Abubakar, (2016), who reported 3.33% higher drag reduction at 5o inclinations over horizontal flows in a 30.6 mm ID pipe. These results essentially indicate that inclination enhanced drag reduction for the systems studied.

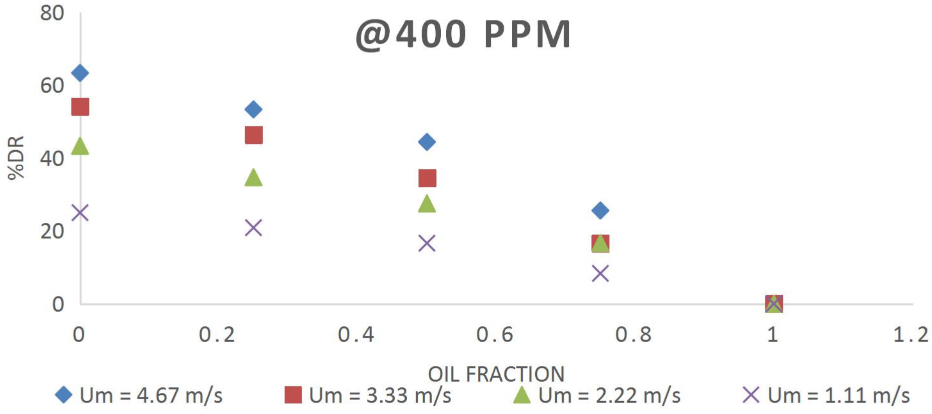

Figure 5: Effect of oil fractions on drag reduction at various mixture velocities and 20 declination

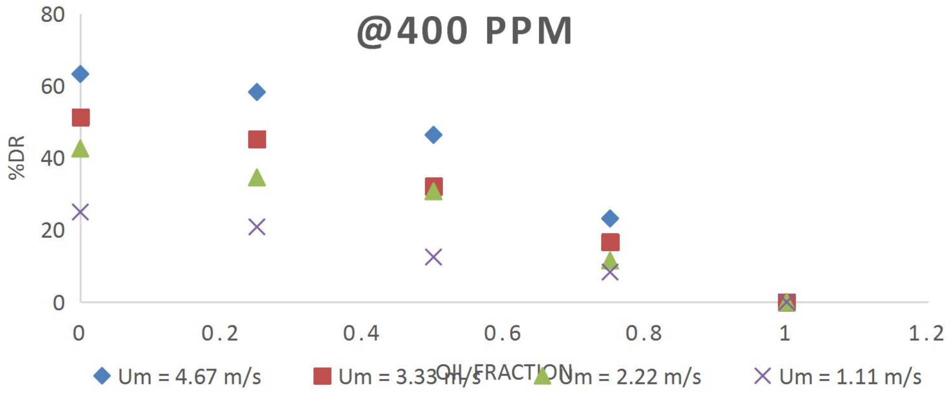

Figure 6: Effect of oil fractions on drag reduction at various mixture velocities and 50 declination

Figures 5 and 6 show the drag reductions measured at various input oil volume fraction and mixture velocities, for 2° and 5° declinations, respectively. The highest drag reductions observed for both 2° and 5° declinations were at zero oil fractions and were equal at were about 63.33%. However, it is observed from figures 5 and 6 that the drag reductions at oil fraction of 0.25 for 2° and 5° declinations at Umix = 4.67 m/s were 53.3% and 58.33%, respectively, within experimental error (a slight 5% difference). These results show slight increase in drag reduction for the 5o over the 2o case. This may be attributable to the greater gravitational flow component in the 5o case as there is increased turbulence in this case that can lead to more mixing of the phases, thus reducing the amount of oil in contact with the pipe walls (drag-inducing flow reduces), consequently reducing the total pressure drop and thus increasing the drag reduction, of the system.

A further comparison of the horizontal flow system (Figure 3) with the declination flows (Figures 5 & 6) showed mixed results. For instance, in the case of 400 ppm, Um=4.67 m/s, the horizontal, 2° and 5° declined flows show drag reductions of 53.8%, 53.3% and 58.33% respectively. This

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shows that a declination of 2° affected drag reduction similarly to horizontal flows and a further declination to 5° yields slightly higher drag reduction than horizontal flows and also slightly higher than 2° inclination (55.75%). This may occur due to the fact that as flow is aided by gravitational forces, increased turbulence in the system can lead to uneven mixing. Which in turn could lead to the DRA not uncoiling as effectively as in the horizontal set-up. Thus being less effective when absorbing the energy of the flow; as such, hindering drag reduction. Thus indicating that declination is not favorable for drag reduction. In addition, the angle of inclination itself did not seem to significantly affect drag reduction.

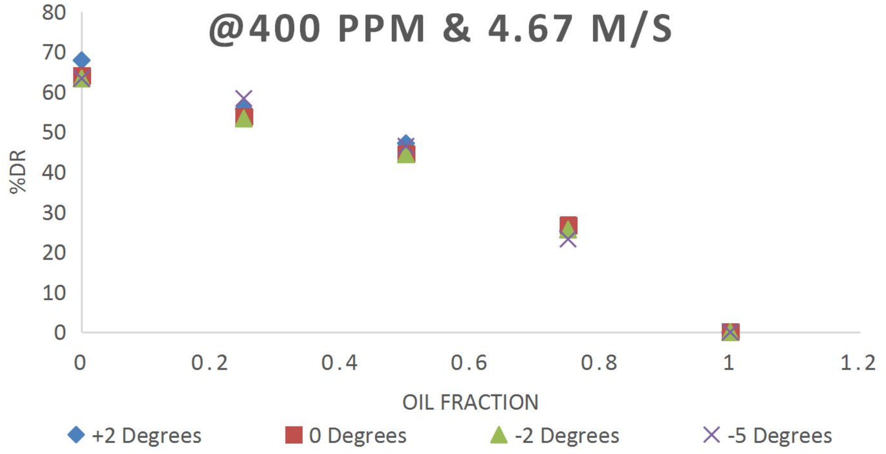

Figure 7: Effect of angle of inclination on drag reduction

Figure 7 shows us that although inclination altered the effectiveness of drag reduction, it did so to minimal degree, despite the introduction of the gravitational component to the flow system. As the high velocity within the pipe negates a significant amount of the phenomenon observed.

4. Conclusion

From all the experiments carried out (testing the viability of Aloe Vera as DRA in oil-water flow) and the results obtained, the following conclusions can be drawn:

A maximum drag reduction of 64% was achieved using a 12 mm ID pipe in single phase water flow; agreeing with earlier work done by Abdulbari (2011) as similar conditions were used.

Drag reduction increased as Reynolds number increased until a Reynolds number of 62,949 was reached. Indicating that the mucilage is a viable drag reducing agent only for Reynolds numbers below 63,000

Multiphase flow experiments showed that the addition of the DRA only affected the water-dominated flow regions. Indicating that drag reduction is only possible when the DRA is soluble in the fluid being transported.

Drag reduction reduced as the oil fraction increased. Maximum drag reduction of 53.80% was achieved at an oil input fraction of 25%

The effect of pipe inclination was significantly negated by the high velocity within the system. Indicating that the DRA can viable for most pipe orientations.

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When used at Reynolds numbers below 63,000, Aloe Vera proved to be an effective DRA in oil-water flow, thereby providing a biodegradable alternative to the synthetic polymers more commonly used.

The synergistic effect of the mucilage should be studied, to further enhance its viability as a bio-degradable alternative to synthetic polymers.

The findings obtained add substantial data to the study of drag reduction, as we strive towards understanding the dynamics and most importantly, the mechanisms of drag reduction.

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