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Performance of Natural and Synthetic Polymers for Drag Reduction on Inclined Pipes for Produced Water in Flow System

A. Ahmed[1], A. Abubakar[1*], L. C. Edomwonyi-Otu[1, 2], N. Yusuf[3]

[1]Department of Chemical Engineering, Ahmadu Bello University, Zaria, Nigeria
[2]Department of Chemical and Petroleum Engineering, Delta State University, Abraka, Nigeria
[3]Department of Chemical and Petroleum Engineering, Bayero University, Kano, Nigeria
*Corresponding Author, Email: abubakara@abu.edu.ng, +2348036951137

Abstract

The major challenge in petroleum and gas industries is high energy demand. The performance of natural (okra) and synthetic polyethylene oxide (PEO) polymers for drag reduction on inclined pipes for produce water in flow system was studied using experimental flow facility of unplasticize polyvinyl chloride (uPVC) pipes of 12 and 20 mm internal diameter (ID). The concentrations of 5 – 50 ppm for synthetic and 100 – 500 ppm for the natural polymers at 0.5 – 2.0% oil fraction (α) were investigated using Reynolds number (Re) of 81,425. Bonny light crude oil (density ρ_o= 862 kg/m^3, at 30°C dynamic viscosity μ_o= 4.5 x 10^{-3}Ns/m^{2}at 30°C) and water (density ρ_w = 1000 kg/m^3, dynamic viscosity μ_w= 0.91 Ns/m^2 at 25°C) used as test fluids. The Δp measured with the use of U-tube manometer for different pipes inclination (+2°, -2°, and -5°).Maximum drag reduction (DR) of 68% PEO at total concentration (tc) of 30 ppm for +2°inclination in 12 mm ID was higher than the value obtained in 20 mm ID at same Re and α of 37,773 and 0.005 respectively. Oil concentrations increases from 0.005 to 2 in the produced water with decreased in % DR. Okra, showed 58% DR lower at 300 ppm tc for same condition of PEO. However, results for -2° and -5° inclinations for PEO slightly varied by 64% and 55% at same Re and α respectively. Lower magnitude of 48% and 32% DR was recorded for okra mucilage. This result showed that inclinations and pipe diameter affect DR on produced water irrespective of the polymer type.

Keywords: Drag reduction, Inclination, Produce water, Polymers

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1 Introduction

One of the key operations in petroleum and gas industry is the pipelines transportation of fluids over a long distance. The turbulent nature of the transporting liquid is the main cause of the pressure drop. It is a well-known fact that the addition of very small amounts (parts per million) of some polymeric materials can drastically minimize frictional pressure loss in pipes and related pumping requirements (Edomwonyi-Otu, 2015).
The phenomenon of drag reduction is the most common example of polymer application was first observed by British chemist Toms in 1948. Thirty years later he proved that introduction of 10 part per million of polymer (methyl methacrylate) into pipeline system drastically reduces the frictional pressure loss in pipe flow by up to 80%, thus increasing pipeline throughput and eliminating the need for addition of pump station this application was first applied by Trans Alaskan Pipeline System in July 1st, 1979. (Leksono, *et al*., 2018)

The effect of DRPs cannot be underestimated considering the economic advantage recorded over the years both in terms of increase in production rate and significant frictional pressure losses. Results showed that offshore production sites experienced greatest challenges in overcoming high pressure losses in multiphase flow pipelines. (Abubakar *et al*, 2014).
At subsea production sites in most petroleum industries the produced water generated requires new approach in reducing the cost of the transportation because of the increasing distance between the processing facilities and production sites. The use of DRPs in such applications could have some economic advantages.

Drag reducing polymers are categorize into two major part artificial drag reducing polymers such as PEO, Partially hydrolyzed polyacrylamide (HPAM) among others and Natural drag reducing polymers like Aloe Vera mixture (AVM), carboxymethyl cellulose, guar gum and others. It has been found that the effectiveness of synthetic polymers (HPAM and PEO) in drag reduction performance is more than that of natural polymer because natural polymers are more rigid and environmentally friendly (Gimba *et al*, 2017).

Consequently, because of their many benefits, drag reduction has found applications in various fields of application it provide

ease of production, minimizing pipeline pressure for constant throughput and reducing operational cost. (Edomwonyi-Otu, 2015).

The influence of using drag reducing polymers (DRP) in different pipe diameters were reported by many researchers (Karami and Mowla, 2012; Yusuf *et al*., 2013; Abubakar *et al*., 2015a;Edomwonyi-Otu *et al*., 2016; M. M. Gimba et al., 2019).

An experimental study was conducted on air-water flow by Al-Sarkhi et al. (2011) to determine the effect of pipe inclination and the performance on drag reduction polymers. The experimental results showed that at an inclination angle of 1.28◦ for concentration of 100 ppm of the polymer a maximum drag reduction of 71% was recorded while lowest drag reduction at higher pipe inclination of 2.4◦ was obtained. The polymer absorbed the turbulent eddies which are the cause of drop formation that lead the water film to spread upward around the pipe wall. They concluded that in general, the higher the inclination angle, the lower the drag reduction. Also, apart from its effect on drag reduction they observed that pipe inclination influences the flow patterns of air-water flow.
In single and multiphase flow the pipe inclination can influence the drag reduction performance depending on the degree of pipe orientation and its diameter. For instance, (Kang and Jepson1999, 2000) conducted experimental study on gas–liquid flow in a 10-cm ID pipe oriented at 2◦and horizontal directions using an un-named DRP. The results showed that there was more drag reduction in the horizontal configuration than in the inclined one.
Another similar study is the investigation carried out by Abubakar *et al*. (2015) they investigated the influence of a drag-reducing polymer on oil–water flow patterns and pressure gradients in downward-inclined pipe (−5◦) and compared with the results obtained in a horizontal pipe for the same flow characteristics. The results showed that the drag reduction at the downward inclination increased with increase in the mixture velocity but decreased with increase in the oil volume fraction at the water-dominated regions.
The effect of polymers on produced water transportation for different pipes diameters and inclinations from offshore to the processing facilities is very important in reducing operation cost for most petroleum industries. Evaluating the effect of inclination of different pipes diameters would provide information for accurate prediction of drag reduction models in drag reduction phenomenon. However, in open literature despite many works on the influence of pipe diameter on drag reduction for oil-water mixture theirs was scanty reports on the effect of DRA on produced water ranges from 0.5 – 2.0% oil-water mixtures as against 2.5 - 10% oil-water mixtures extensively reported in many literatures. Thus, the motivation of this research is to source more data on the study of the influence of pipe diameter on drag reduction in produced water flow system using PEO and okra mucilage polymers.

1.1 Experimental Method

The experimental flow loop facility is design to handle horizontal and incline flow operations. As shown in figure 1. It is divided into three main parts: the handling section, pumping or regulating section, and the flow measuring section.
The fluid handling section consisted two tanks for the working fluids: which were tap water and crude oil. The capacity of each tank was 200 liters and each of them was separately connected to the pump (model Jet 102M/N.31227) used for circulation of both fluids into their respective storage tank. Flow meters which were used to meter the oil and water could operate at maximum flow rate of 65 l/min, speed of 2,800 rpm, 45 m head. A gate valve was also situated just before the flowmeter for regulating the flow rate since the pump was operating at full capacity. The pipes connecting the oil tank and water tank to the pumps was made up of unplasticized Polyvinyl Chloride (uPVC) of 12 mm and 20 mm internal pipe diameter (ID).

The size of the separator tank was 250 liters capacity and the separation was influenced by gravity such that the water being denser was at the bottom while the oil being lighter was at the top. It was designed to allow for the separated water to be drained out of water tank while the separated oil to be returned to the oil handling tank. The oil flowmeter valve was closed since only water flowmeter is needed for the experiment.

The test section is made up of straight pipe of 140 times the diameter of pipe (140D) long to the second pressure port and the acrylic pipe of different ID of 12 mm and 20 mm. U-tube mercury manometer was used for pressure drop measurements across the test section. The centrifugal pumps deliver the test fluids through a 20 mm outlet and passes through the flow meter to the test section. The pressure drop (Δp) taps are 0.5 m apart in the viewing box (uPVC acrylic pipe) for 12 mm and 20 mm ID. The pump used for injecting the polymer solution at a specific flowrate at polymer injection point located just before the Y- junction. It was peristaltic pump (model: NE-9000) with flow rate ranging from 0.035mL/min to 775.2 mL/min.

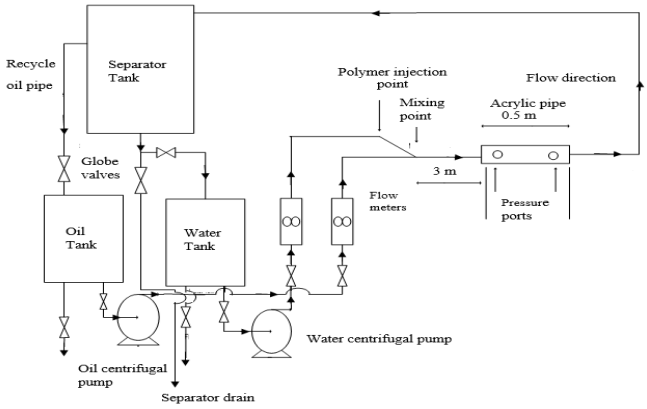

Figure 1: Schematics of experimental flow rig

1.2 Polymer Preparation

The polymers used are polyethylene oxide (PEO) manufacture by Sigma-Aldrich with average molecular weight of 8 x 10^6g/mol, and Okra *(Abelmoschus esculentus)* mucilage extracted from okra plant. The two polymers are water soluble and were used without further purification.
A master solution of 1000 ppm were prepared for the PEO.

The polymer powder of 5 g portion was weighed using (Kerro, BLC 3002) weighing balance and gently mixed in 5 liters of water while stirring slowly using mechanical stirrer of (Gilverson, L28)for 1hour to avoid degradation of polymer and the mixture was allowed to homogenized completely. To get the master solution of 1000ppm the solution was kept for 24 hours in order to achieve complete dissolution of the polymer particles.

2000 ppm of okra mucilage was prepared by using 10g of chopped okra was mixed with 5 liters of distilled water for one hour. The mixture was then heated, stirred moderately and was allowed to stay for 24 hours to further enhance and speed up the extraction process. The extract from the okra produces a clear thinning viscoelastic color called mucilage which later sieved using muslin cloth so that no foreign or suspended particles pass through with the jelly mucilage.

The preliminary experiments was conducted with each polymer in single phase flow, and the total concentration (tc) for each mixture was established such that maximum DR of each polymer mixture was obtained at that concentration (Ginmba *et al*., 2017).
In the case of this present work the total concentrations of 400 ppm and 30 ppm for Okra mucilage and PEO were use respectively.
The (oil-water) concentrations were prepared in the water tank using mixer (HM-20) at 12400/rpm for four different oil fractions (0.005,0.01,0.015 and 0.02) each oil-water fraction runs at four different flow rates (10,20,30 and 40lit/min).To prepare (simulate) a produced water of 0.005 (0.5 %) oil fraction, 1 liter of crude oil was poured into 199 liters of water (making a total of 200-liter oil-water mixture) and then stirred using a mixer to agitate and disperse the oil evenly into the water for at least 20 minutes. Similarly, for 0.01 (1 %) oil fraction, and by pouring 2 liters of crude oil into 198 liters of water to produce a 200-liter oil-water mixture and then stirring for another 20 minutes, this was repeated for the subsequent oil fractions of 0.015 and 0.02 with 3 and 4liters of oil to make the produced water.

2 Procedure

To ensure accurate injection of the required amounts of polymer solution into oil-water mixture (produced water) through the test section, the injection pump and flow meters were calibrated before starting the experiments. The experiment was carried out in three different inclinations +2°, -2° and -5° pipe diameters of 12 and 20 mm ID and length of 140*D at ambient conditions (25°C, 1 atm). The U-tube manometer was used for the pressure drop measurement. The experiments were performed at least three times with a standard deviation of less than 3.5%.At +2° inclination the PEO was tested in 20 mm ID pipe diameter at different polymer concentrations of 5-500 ppm at flowrate of 10, 20,30 and 40lit/min. and Reynold number (Re) from 12916 – 48871. The total concentration from preliminary experiment was 30 ppm as optimum polymeric concentration (Gimba *et al*., 2018).At optimum of 30 ppm PEO was tested for each oil fractions α=0.005, 0.01, 0.015, 0.02 and Re =12916- 48871.The same procedure was repeated with 12 mm ID pipe at same operating conditions but higher Re from 21519-81425, for +2°, -2° and -5°inclinations. While for the okra (natural) at 400 ppm in 12 and 20 mm ID pipesfor the same conditions and procedure was applied. The pressure drop was recorded using u-tube manometer for calculations of the DR; defined by the given equation 1 below:

$$DR = \frac{\Delta Pwo - \Delta Pw}{\Delta Pwo} \quad (1)$$

Where; ΔPwo and ΔPw is pressure drop of the fluid without and with DRPs.

3 Results and Dıscussıon

In Figure 2 showed the effect of DR studied in 12 and 20 mm ID pipes at -2°inclination (downward inclination) on produced water. DR obtained at same oil fraction (α=0.005) and Re 37773 slightly varied by 48% in 12 mm ID pipe while 44% in 20 mm ID at maximum polymer concentration of 30 ppm PEO. This may be due to the increase in velocity in the smaller pipe thus increase the interaction between the polymer and the turbulence in the mixture. However, at higher Re 48872 in 20 mm ID pipe %56 DR reached plateau value such that further increase in the velocity would have no effect on the DR in same α=0.005, while maximum of 64% DR was obtained in 12 mm ID at higher Re 74804.

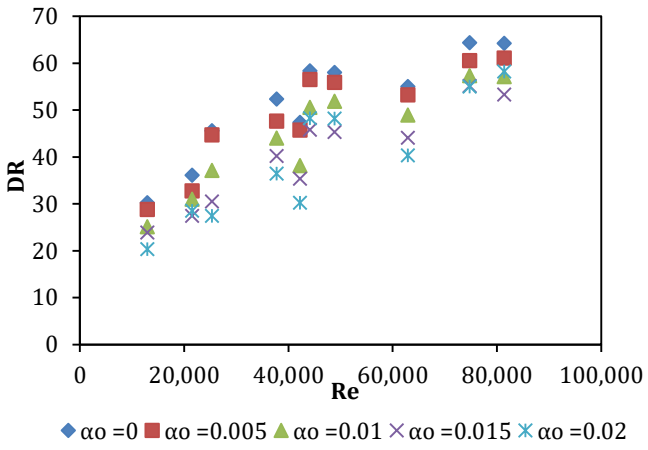

Figure 2: DR in produced water against Re as a function of oil fractions in 12 and 20 mm ID pipes diameters for **PEO** at -2°inclination

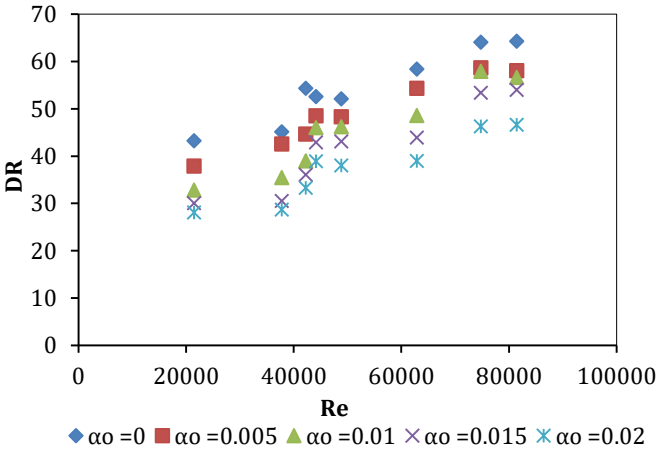

Figure 3: DR in produced water against Re as a function of oil fractions in 20 mm ID pipe and 12 mm ID pipe for **okra mucilage at 400 ppm** at -2° inclination.

In Figure: 3. The DR obtained with PEO is slightly higher in magnitude than that obtained with okra mucilage even at same conditions as shown in figure 3 above. Example, Drag reduction of 43% and 28 % in 12and 20mm ID pipe diameters respectively at R 37773 for the same α=0.005 and inclination of -2°. This may be due to the degradability of the okra mucilage and its lower molecular weight when compared with the PEO (synthetic) as reported by Abdulbari *et al*. (2012).

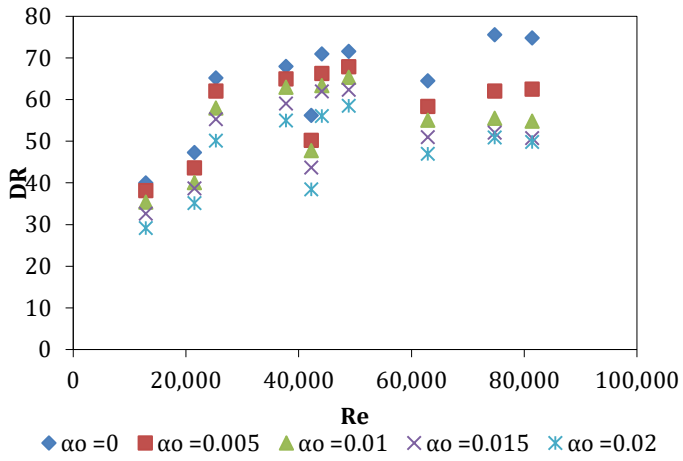

Figure 4: DR in produced water against Re as a function of oil fractions in 12 and 20 mm ID pipes diameters for **PEO** at +2°inclination.

In Figure4: The results for upward inclination at +2° is relatively affected by the introduction of gravitational pressure gradients and this will increase the overall pressure gradients and decrease for downward declination (Abubakar et al., 2015) as can be seen in this case. The values of DR of 62% in 20 mm ID and 65% in 12 mm ID at same Re 37773 showed slight increase when compared with the values of DR obtained for same oil fraction in Fig. 2 This is in agreement with Al-Sarkhi et al.(2006) where they concluded that the higher the inclination angle, the lower the drag reduction.

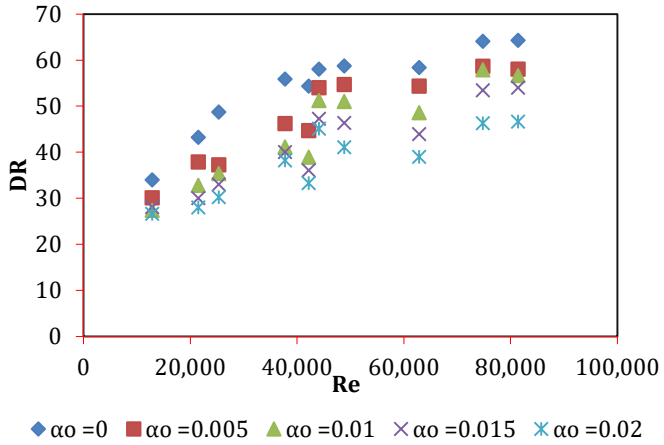

Figure 5: DR in produced water against Re as a function of oil fractions in 12 and 20 mm ID pipes diameters for **Okra mucilage** at +2°inclination.

The variation of DR obtained for okra mucilage at same inclination recorded slight degradation at high Re unlike the synthetic (PEO) as reported by Al-Saraki et al. (2006).As indicated in the Figure 4 above 46% and 55% DR at R37773 for same oil fraction α=0.005 and inclination a slightly lower drag reduction was recorded when compared with the values of %DR obtained with PEO in Figure 4. Also, the difference in %DR occurred due to increase in gravitational pressure gradients by +2 ◦ upward inclination.

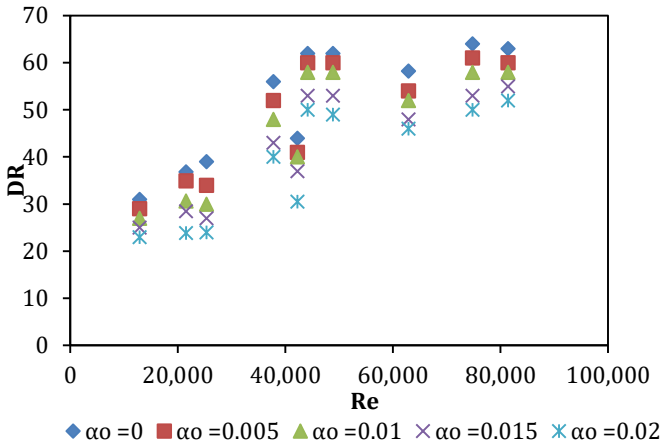

Figure 6: DR in produced water against Re as a function of oil fractions in 12 and 20 mm ID pipes diameters for **Okra mucilage** at -5°inclination.

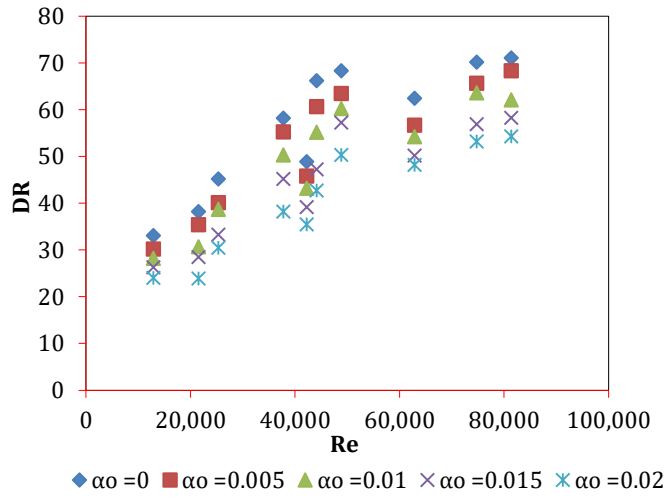

Figure 7: DR in produced water against Re as a function of oil fractions in 12 and 20 mm ID pipes diameters for **PEO** at -5°inclination.

However, in figure 7 slightly higher drag reduction of 58% and 54% was recorded in 12 and 20 mm ID pipes respectively this corroborate with work reported by Gimba et al.,(2018) where he established the performance of DR in synthetic polymer (PEO) as relatively higher than natural (okra) polymer even at same inclination and oil-volume fraction. The Addition of the PEO in fig. 7 did not significantly change the effect of the -5° downward inclination when compared with -2° downward inclination.

4 Conclusion

The effects of drag-reducing polymer on produced water flow at upward and downward-inclined pipes were investigated experimentally and compared with following conclusions:

For downward inclination (-2°) in fig. 2; for oil fractions α=0.005 at Re 37773, the DR 48% and 44% in 12 and 20 mm ID were obtained, while at higher Re 48872 for same oil fraction 64% and 56% DR in 12 and 20 mm ID were obtained with PEO respectively. However, in fig.3 using the okra mucilage at same conditions of fig. 2 the PEO 43% and 28 % DR in 12 and 20 mm ID were observed respectively.

At upward inclination (+2°) in fig.4; for same conditions in fig 2, using PEO 65% and 62% DR in 12 and 20 mm ID was recorded respectively. While, that of okra mucilage in fig. 5 at same conditions were 55% and 46% DR in 12 and 20 mm ID respectively.

Similar observation was recorded in (-5°) inclination in fig. 6 for PEO with 48% DR, when compared with (-5°) inclination in fig.7 for okra mucilage with 58% DR in 12 mm ID downward inclination at same conditions. Hence;

- The DR at the downward inclination increased with increase in the gravitational pressure gradient irrespective of the polymer type. However, okra mucilage showed low DR performance when compare with PEO polymer.
- The drag reduction performance at downward-inclined flow has relative influence when compared with that of upward inclination.
- The mixture velocity determines the effective drag reduction performance in the two different pipes diameters, the smaller the pipe diameter the higher the DR effectiveness.

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