



Original Research Article

Drag Reduction Performance of Natural Gums in Oil-Water Flow through Pipes of Different Diameters

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ABSTRACT

An experimental investigation of the effect of two natural water-soluble polymers (Xanthan gum and Guar gum) on drag reduction was studied in flowing oil-water flow system. The study was carried out in horizontal pipes of internal diameter 12 and 20 mm. The test fluids were oil ($\rho = 832 \text{ kg/m}^3$; $\mu = 3.5 \text{ cP}$ at 25°C) and tap water ($\rho = 998 \text{ kg/m}^3$; $\mu = 1.0 \text{ cP}$ at 25°C). Different concentration, mixture velocity and the input oil volume fraction were investigated. 10,000 ppm master solution of the individual polymer concentrations were used in the single-phase water flow with concentrations ranging from 50 ppm to 250 ppm. Optimal polymer concentration of 200 ppm and 150 ppm was established for xanthan gum and guar gum respectively. The experimental results also showed that drag reduction (DR) of the individual polymer increased with the increase in additive concentrations and Reynolds numbers (Re) but decreased with the increase in the oil fractions. In addition, the drag reduction increased with increasing pipe diameter irrespective of Reynolds number.

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1. INTRODUCTION

Liquids transportation through pipelines over long distances is considered one of the most power consuming sectors in the industry due to the turbulent mode these liquids are transported within (Abdulbari *et al.*, 2012). Supporting pumping systems used to overcome these problems constitutes high percentage of the world's electricity demand (Hameed *et al.*, 2014). Experimental studies by Abdulbari *et al.*, (2012), Edomwonyi-Otu and Angeli (2014), Edomwonyi-Otu *et al.*, (2015) and Yang 2015 showed that the addition of small concentrations of certain additives in parts per million (ppm) to the turbulent flowing liquids can greatly decrease frictional pressure loss. This phenomenon called drag reduction, has found wider uses in industries to increase the flow capacities of existing pipelines. It can also be used to reduce supply pressures, pumping

costs, and pipe diameters for given flow capacities (Abdulbari *et al.*, 2012). It was recently suggested for use in the transportation of drinking water due to its harmless properties (Edomwonyi-Otu and Adhlakun, 2018).

Drag reduction additives can be divided into five categories, namely; polymers, surfactants, fibres, micro-bubbles and compliant coating (Abubakar *et al.*, 2015). Among them, polymers, surfactants and fibers are the most studied additives. However, drag reduction using polymers has received much attention at industrial level due to its advantage of being applied in very small quantities (Abubakar *et al.*, 2015). Experimental evidence shows that the polymer increases the thickness of the viscous sub-layer and the transition zone. The mechanism of this boundary layer effect is not yet fully understood, but supporting experimental evidence has been given by some researchers (Lumley, 1969; Tabor and De Gennes, 1986; Singh, 2004).

Although some studies on drag reduction in multi-phase flows using synthetic polymer solutions are available in the literatures (Al-Wahaibi *et al.*, 2007; Mowla and Naderi, 2008; Al-Yaari, 2009; Edomwonyi-Otu 2015; Abubakar, 2016 and Eshrati *et al.* 2017), little or no attempts have been made to study the effect of natural drag reducing polymers (DRPs) in oil-water flow. This present work involves the use of water soluble natural polymer as drag reducing agent in oil-water flow. Two different internal pipe diameters were used to investigate the concentration effect. The efficiency of natural gums was tested in oil and water mixture.

2. MATERIALS AND METHODS

2.1. Materials

Analytical grade Guar gum and Xanthan gum were obtained in powdered form from Cardinal Chemical Supply Store, Zaria. Guar gum is a galactomannan polysaccharide produced from the seeds of *Cyamopsis tetragonolobus*, a member of Leguminosae family while Xanthan gum is a natural extracellular heteropolysaccharide produced by the fermentation of the bacteria *Xanthomonas campestris*. Figures 1 and 2 show the chemical structure of the polysaccharides in the Guar gum and Xanthan gum mucilage respectively.

The transported fluids used were tap water sourced from Chemical Engineering Department, Ahmadu Bello University Zaria, Nigeria and oil (diesel) supplied by Kaduna Refining and Petrochemical Company (KRPC), Kaduna, Nigeria. The physical properties of water and diesel are shown in Table 1. All samples were used as received without further purification.

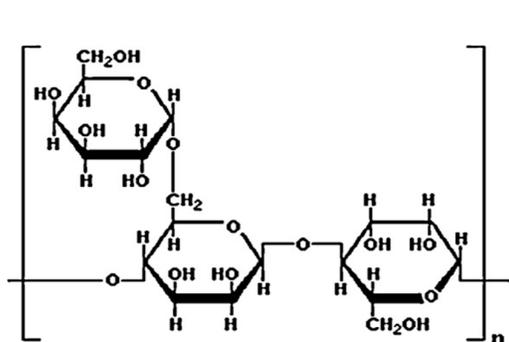


Figure 1: Chemical structure of Guar gum (Abdulbari *et al.*, 2014)

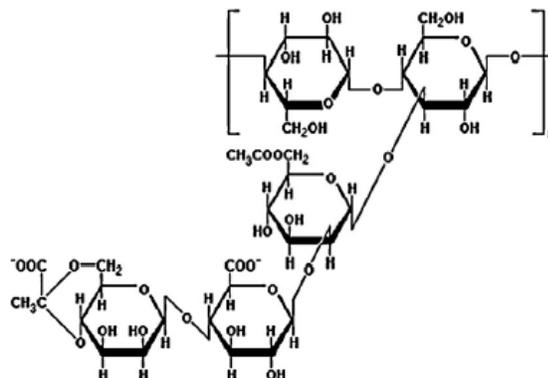


Figure 2: Chemical structure of Xanthan gum (Abdulbari *et al.*, 2014)

Table 1: Physical properties of the test fluids at 25 °C

Property	Water	Oil
Viscosity (cP)	1	3.5
Density (kg/m ³)	998	832

2.2. Experimental Setup

The flow facility used for this study is located in the Multiphase Flow Laboratory, Chemical Engineering Department Ahmadu Bello University Zaria, Nigeria. The drag reduction experimental study for pipe diameter (D), volumetric flow rate and the additive concentrations was carried out in a built-up closed loop liquids circulatory system shown in Figure 3. The rig consists of three sections namely handling, regulating and test sections. The fluids handling section consists of a gravity separator with a capacity of 220 litres and two tanks each with a capacity of 200 litres for diesel and water respectively connected with the recirculation pipe used to control the liquids flow rate entering the system. The regulating section comprises two centrifugal pumps (model: Jet 102M/N.31227) used to circulate the fluids, an ultra-flux portable flow meter (model: LZM-20J) to measure the flow rate and valves for controlling the flow rates. The test section consists of two visible un-plasticized Polyvinyl Chloride (uPVC) pipes of 12-mm and 20-mm internal diameter (ID) and joined together by flanges for easy dismantling, a U-tube manometer (Pyrex) with mercury as the manometer fluid for the measurement of pressure drops, a new Era Pump System (model: NE-9000) with accuracy of $\pm 2\%$ for injecting polymer into the test section. Each test section is supported with a ball valves used to close and open the testing section stream.

In each pipe, the first testing point starts after 140 times the pipe diameter to ensure turbulent flows are fully developed before the testing process run. Hence, the first pressure port is located after 140 times the pipe diameter, i.e., 1.68 and 2.8 m for pipe with ID of 12 and 20 mm, respectively. Each pipe is designed with two pressure ports 0.5 m apart. The U-tube manometer was connected to the pressure ports to measure pressure drop. The energy required for the centrifugal pump is 0.75 kW and the pump voltage is 220 – 240 V. The flowmeters of each fluid were calibrated before the start of the experiments with obtained R^2 values greater than 0.98.

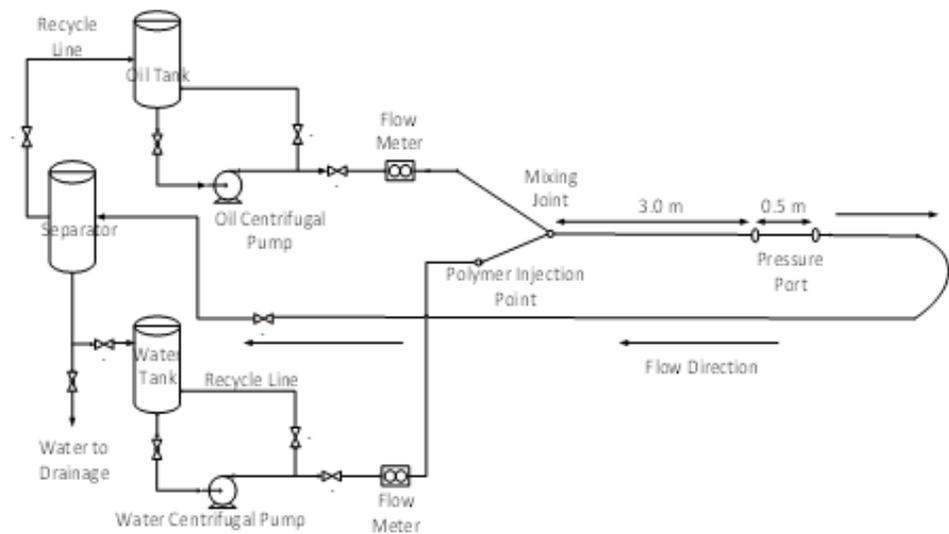


Figure 3: Schematic diagram of the multiphase flow loop

2.3. Experimental procedure

2.3.1. Polymer preparation

The preparation of the polymer solution was carried out according to the method of Venugopal and Abhilash, (2010). A master solution of each polymer was prepared by weighing out 30 g of the respective powdered samples using an electronic balance (CWS Series) and gently sprinkled into 3 litres of tap water in a vessel. The mixture was slowly agitated for about 4 hours and then allowed to stand for about 12 hours for proper hydration of the polymer particles.

2.3.2. Determination of intrinsic viscosity and molecular weight

The viscosity of dilute solution of the polymers having 0.01, 0.02, 0.03, 0.04 and 0.05 g/dl concentrations were examined using Ostwald viscometer. Measurements were performed using 50 ml of the sample solutions. Flow rates of the successive dilutions (0.01 – 0.05 g/dl) as well as pure solvent (water) were noted in triplicate at room temperature and the average of these three readings were recorded. The viscosities of these solutions were then calculated from which the intrinsic viscosities were determined by taking specific viscosity at various concentrations and extrapolating the concentration to $c = 0$. From the intrinsic viscosities, the molecular weight was estimated using Mark-Houwink's equation as shown in Equation (1).

$$[\mu] = KM^a \quad (1)$$

Where:

$[\mu]$ = Intrinsic viscosity
 M = Molecular weight of the polymer
 K = Proportionality constant
 a = Shape factor

'K' and 'a' are also called Mark-Houwink constants and their values are obtained from the literature as $K = 3.800 \times 10^{-4} \text{dl/g}$ and $a = 0.732$ for Guar gum (Venugopal and Abhilash, 2010) and $K = 2.7900 \times 10^{-7} \text{dl/g}$ and $a = 1.2754$ for Xanthan gum (Martin, 2014).

2.3.3. Pressure drops measurement

The single-phase water flow and multi-phase oil-water flow experiments were carried out in the piping apparatus shown in Figure 3. The single-phase experiment was first conducted using water flow rates in the range of 10 to 35 l/min and the polymer concentrations tested were varied from 50 to 250 ppm. The injection rate for the required polymer concentration in the flow system was calculated using Equation (2).

$$Q_p = \frac{C_1 \times Q_w}{C_m - C_1} \quad (2)$$

Where Q_p is the polymer flow rate, C_1 is the required in-situ polymer concentration in the test section, C_m is the concentration of the polymer master solution and Q_w is the water inlet flow rate (Edomwonyi-Otu, 2015).

Flow rate, Q of water circulating in the apparatus was measured using a non-invasive, ultra-flux portable flow meter. At a fixed flow rates before adding polymer solution, pressure drop readings were taken once Q was relatively constant using the U-tube manometer. Thereafter, at the same flow rates, the pressure drop values were taken at various polymer concentrations. This procedure was repeated for all the water flow rates investigated.

Next, the multi-phase oil-water flow experiment was carried out at variable mixture velocity (U_m) and input oil volume fraction (α_o). The experiments were carried out at intervals of about 50 minutes to prevent overheating of the oil phase by the centrifugal pump. For each experimental run (i.e. a mixture velocity at a fixed input oil volume fraction), the oil was first pumped from its storage tank to the regulating section where it was metered and then transferred to the test section. Thereafter, the water was similarly pumped, metered and it got mixed with the oil at the Y-junction before they are transferred together to the test section. After attaining steady state within a minimum of five minutes, the pressure drop was measured. The master polymer solution was then injected to the water flow line before the oil-water mixing at the Y-junction, and at a specific flow rate to achieve that specified polymer concentration in the main water flow line and the pressure drop also measured. This was done for each polymer solution separately.

The same experimental procedure was repeated for different combinations of oil and water flow rates. Reproducibility of the experimental data was checked by performing the experiment in triplicate and average was taken.

The drag reduction can be computed by the percentage of pressure drop difference upon the addition of polymer solution using Equation (3).

$$\%DR = \frac{\Delta P_o - \Delta P}{\Delta P_o} \times 100 \quad (3)$$

Where ΔP_o and ΔP represent the measured pressure drop without and with the addition of drag reducing agent (DRA).

3. RESULTS AND DISCUSSION

3.1. Intrinsic Viscosity and Molecular Weight

Intrinsic viscosity was determined from the viscosities of the polymer solutions and that of the solvent (water) using Ostwald viscometer. Figure 4 show the plot of reduced viscosity against polymer concentration. From the figure, the intrinsic viscosities for Guar gum and Xanthan gum was determined to be 9.33 and 22.38 dl/g respectively. It is very clear that the intrinsic viscosity of xanthan gum is higher. This might be attributed to the existence of coulomb forces and rigidity of the polymer molecules in the aqueous solution of Xanthan gum (Eshrati *et al.* 2017).

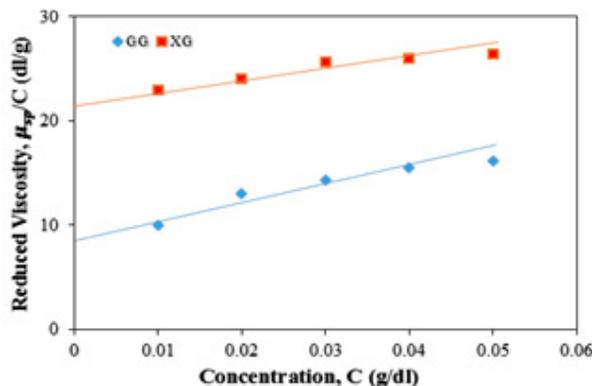


Figure 4: Reduced viscosities versus polymer concentrations at room temperature

From Equation 1, the molecular weight of Guar gum and Xanthan gum was calculated to be 994,035 g/mol and 1,575,695 g/mol respectively, which are close to reported values of 954,000 and 1,675,310 g/mol for Guar gum and Xanthan gum respectively (Mahmoud, 2000; Martin, 2014). The variation in the molecular weight values of the gums reported in literature might be due to the difference in sample and the purification of samples.

3.2. Determination of Optimum Polymer Concentration

The effect of polymer concentration in single-phase water media was investigated at different water velocities expressed in terms of Reynolds number and the result are presented in Figures 5 and 6. The addition of the polymer suppressed the formation of turbulence, hence, reduced the oil-water pressure gradient. From the figures, it was observed that DR increased with increasing polymer concentration before reaching plateau values effectively at polymer concentration of 150 and 200 ppm for Guar gum and Xanthan gum respectively. This is because as the polymer concentration was increased, there were more polymer molecules interacting with the turbulent structures (eddies) inside the main flow system (Hameed *et al.*, 2014). This resulted in increasing the apparent viscosity of the transported liquid and thus the increase in the observed DR. Further increase of polymer concentration beyond these concentrations did not cause appreciable increase in the drag reductions. This is because an optimum additive-liquid balanced concentration was reached after which the viscosity of the transported liquid would no longer change (Abdulbari *et al.*, 2012). In general, based on the experiments conducted, all concentration showed a drastic reduction of drag reduction at Re of 19861 to 69528. These results showed that the optimum performance of the polymers additive investigated is limited to the degree of turbulence, that by increasing the flow, the degree of turbulence will increase also which will provide more suitable environment for the drag reducer to perform. Most of the experimental results agree well with the previous work published by many researchers such as Reddy and Singh (1985), Ram *et al.* (2009) and Kulmatova (2013).

Although the polymer concentration at which maximum drag reductions were achieved differs for both polymers. The reason for the difference might be due to the high molecular weight of Xanthan gum (1,675,310 g/mol) compared to that of the Guar gum (954,000 g/mol). Thus notwithstanding, polymer concentrations of 150, 200 and 250 ppm were selected for subsequent investigations to ensure that maximum drag reductions were achieved.

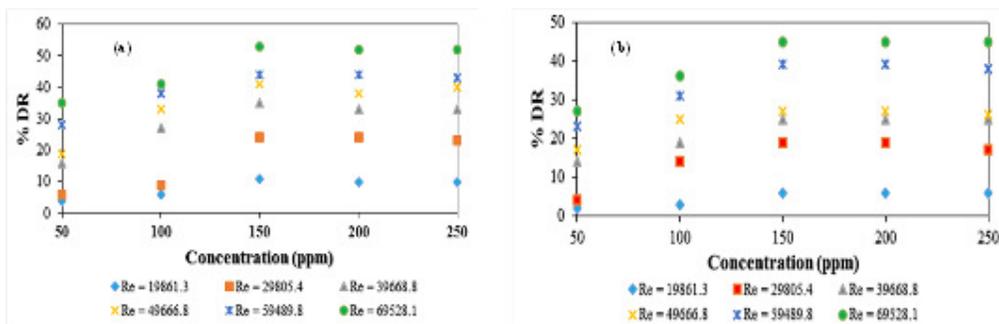


Figure 5: Drag reduction in single-phase water flow at different polymer concentrations and Reynolds numbers through 12-mm ID pipe for: (a) Xanthan gum (b) Guar gum

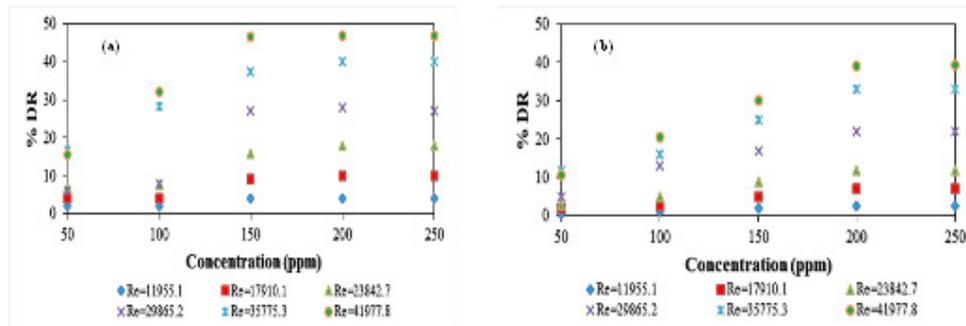


Figure 6: Drag reduction in single-phase water flow at different polymer concentrations and Reynolds numbers through 20-mm ID pipe for: (a) Xanthan gum (b) Guar gum

3.3. Effect of Input Oil Volume Fraction

The effect of input oil fraction (α_o) on DR in two-phase oil-water flow was investigated at different mixture velocities expressed in terms of mixture Reynolds number for different pipe diameters and polymer concentrations and the result are presented in Figures 7 – 9. In general, the drag reduction decreased as the oil fraction increased. This is attributed to the reduced turbulence in the water phase since water-soluble polymers are used as the drag reducing agents. Hence, the increase in the input oil volume fractions reduced the interaction of the DRP molecules with the water phase. Also, from the Figure 8, the addition of 200 ppm of Xanthan gum solution resulted in drag reduction of 23 % with 0.25 oil fraction at mixture velocity of 1.68 m/s. At the same mixture velocity and oil fraction, the addition of the same concentration of Guar gum solution resulted in drag reduction of 18 %. This might be due to its low molecular weight (954,000 g/mol) compared to that of Xanthan gum which is 1,675,310 g/mol.

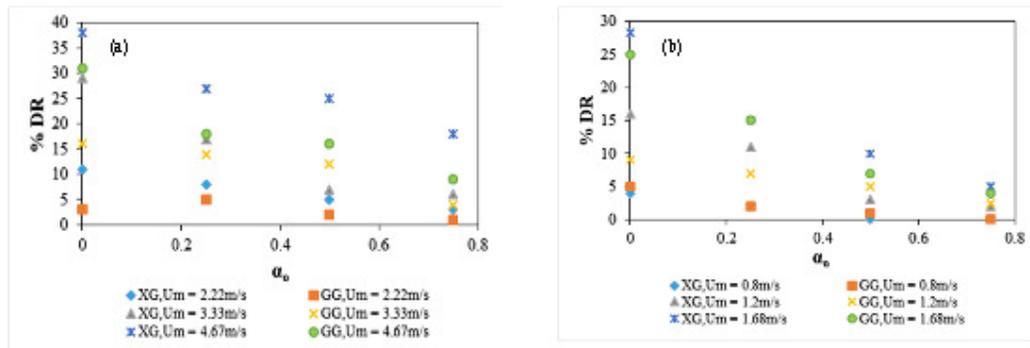


Figure 7: Effect of input oil fraction on oil-water drag reduction at different mixture velocities by 150 ppm DRP for (a) 12 mm I.D pipe (b) 20 mm I.D pipe

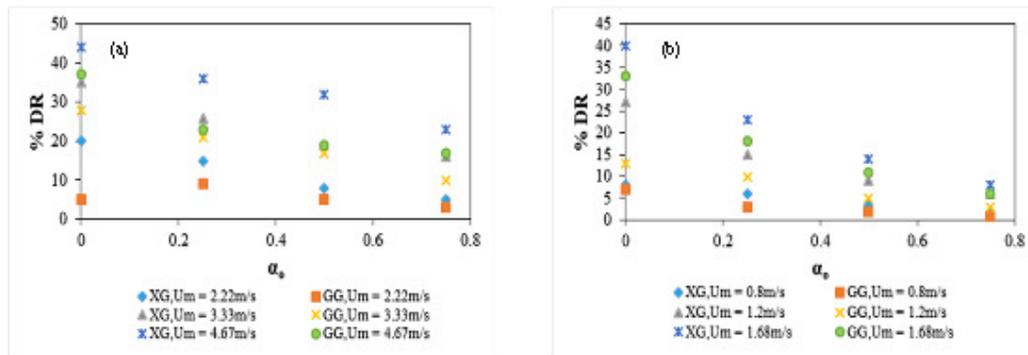


Figure 8: Effect of input oil fraction on oil-water drag reduction at different mixture velocities by 200 ppm DRP for (a) 12 mm I.D pipe (b) 20 mm I.D pipe

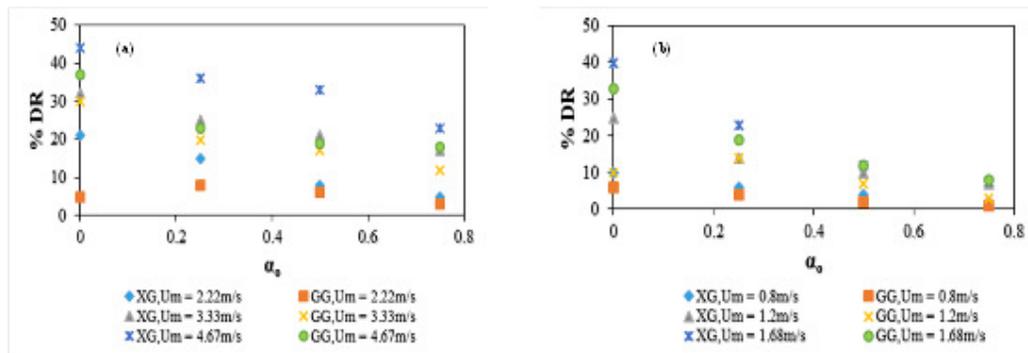


Figure 9: Effect of input oil fraction on oil-water drag reduction at different mixture velocities by 250 ppm DRP for (a) 12 mm I.D pipe (b) 20 mm I.D pipe

3.4. Comparing Drag Reduction Performance in 12 and 20-mm ID Pipe

One of the main factors influencing the drag reduction performance is the effect of pipe geometry. In the present work, two pipe diameters (12 and 20 mm ID) were investigated within all other experimental variables. Figures 10 shows the effect of pipe diameter on drag reduction for Xanthan gum and Guar gum. Generally, drag reduction increases with increase in Reynolds number for both pipes. However, at the same Reynolds number of 35700, drag reduction was higher within the larger pipe (20-mm ID) compared to the smaller one (12-mm ID). This may be due to the change in the space available for eddies to stretch which will lead to the fact that larger and slower eddies will appear in the turbulent flow. It is believed that such eddies are much easier to be suppressed by the DRP due to its low shear intensity. The results obtained did not conform to those presented by Abdulbari *et al.* (2011) who suggested that the drag reduction performance would be higher for lower pipe diameter. Though in their findings, the comparison was done at the same flow rates using Cocoa Husk waste mucilage as the drag reducing agent.

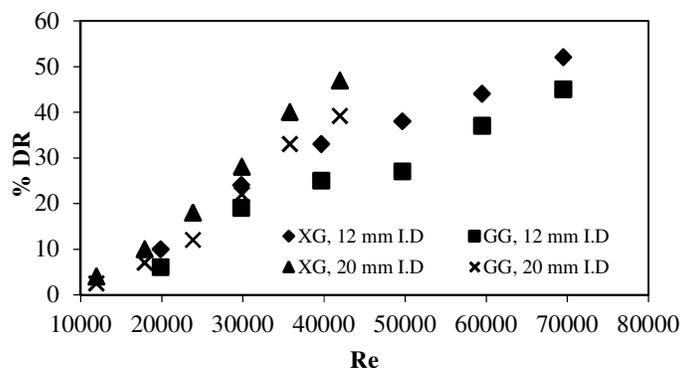


Figure 10: Effect of pipe diameter on oil-water drag reduction by addition of 200 ppm PDRA at different Reynolds number

4. CONCLUSION

From the investigations carried out, the following conclusions was drawn:

- Drag reductions by the natural polymers was found to increase with the increase in the polymer concentration and this becomes more significant as the Reynolds number increases.
- Drag reductions decreased with the increase in oil fraction and this was due to the reduced turbulence in the water phase since water-soluble polymers are used as the drag reducing agents.
- Drag reduction was higher in larger pipe diameters when compared to smaller pipe diameters under the same Reynolds number.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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