COMPARING THE EFFECT OF PIPE DIAMETER AND TEMPERATURE ON THE EFFECTIVENESS OF POLYETHYLENE OXIDE AS DRAG REDUCING POLYMER

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Abstract: This study was carried out to investigate the effect of pipe diameter and temperature on the effectiveness of polyethylene oxide as drag reducing polymer. The flow facility is made from unplasticized polyvinyl chloride (uPVC) pipes of 20 and 12 mm internal diameter (ID), Temperature range of 5 to 60°C, polymer concentration of 5 to 50 ppm and Reynolds numbers less than 100000 were studied using oil [diesel] (density = 832 kg/m^3, viscosity = 1.664 mPa.s at 25°C) and water (density = 1000 kg/m^3, viscosity = 0.91 mPa.s at 25°C) as test fluids. Pressure drop was measured using u-tube manometer. In single phase (water) flow, a maximum drag reduction of 72% (20 mm ID), 76% (12 mm ID) was achieved in horizontal flow at room temperature. Drag reduction decreased from 80.61 to 60% (20 mm ID), 84 to 66.8% (12 mm ID) when temperature was raised from 5 to 60°C. In multiphase flow, a maximum drag reduction of 62.25% (20 mm ID), 65.25% (12 mm ID) (25% oil input, Umix=1.68 m/s, room temperature) was observed. The result show that as temperature increased from 5 to 60°C, drag reduction decreased from 70.83 to 50% (20 mm ID), 73.08 to 54.62 (12 mm ID). Thus, temperature has significant effect on drag reduction but its effect is sparingly higher for the larger pipe diameter.

Keywords: Drag reduction, Drag reducing polymer, pipe diameter, polyethylene oxide

Introduction

Drag reduction is an engineering intervention whereby the frictional pressure drops occurring in a flow system is deliberately reduced or minimized (Edomwonyi-Out, 2015). The aim is to enhance process efficiency and operational flexibility with the aid of active ingredients called drag reduction polymers (DRP) (Edomwonyi-Otu and Angeli, 2019). Drag-reducing polymers generally have linear flexible chain structures with a very high average molecular weight. Polyethylene oxide, a polymer with ethylene oxide as the repeating unit, has been extensively adopted as an effective drag reducer in aqueous systems (Abubakar *et al.,* 2015).

The effects of solutions of five homologous Polyethylene oxide (PEOs) with different molecular weights in distilled water on drag reduction (DR) in a turbulent flow was studied (Virk and Merill, 1969). They found that the strength of the DR produced by the homologous PEOs in a pipe flow is a universal function of the molecular weight, polymer concentration, and flow rate. This was corroborated by a recent report (Edomwonyi-Out, 2019) where two different molecular weight PEOs were investigated. The maximum drag reduction efficiency was possibly limited by an asymptotic value that is independent of the pipe diameter and polymeric species. This experiment also presented the intrinsic concentration, $[C] = RF_{max}/[R]$ (where $[R]$ is the DR value of an initial increment of the polymeric chain) and demonstrated that the DR efficiency increased with a decrease in the diameter of the pipe and increasing polymer concentration.

Similarly, Choi *et al.* (2000) investigated the effect of the concentration of dilute solutions of water-soluble PEO on turbulent DR in a rotating disk flow system. The results demonstrated that the DR efficiency of PEO increased with increasing concentration of PEO, to reach a critical concentration at which the DR was maximal. The DR efficiency then declined with a further increase in the polymer concentration. The optimum critical polymer concentration decreased with an increase in the polymer viscosity-average molecular weight. On the other hand, the appearance of a maximum at 23% was reported to bedue to the DR characteristics of the polymeric solute and the increased solution viscosity, where in both become important at higher polymer concentration.

The potentials of PEO as a drag reducer in seawater piping in an ocean thermal energy conversion (OTEC) process was investigated (Kim *et al.,* 1999), including the drag reducing characteristics and mechanical degradation of PEO with different molecular weights and concentrations. The drag reduction was initially time-dependent and then remained at the limiting value due to degradation of the polymer chains. With the degradation of the polymer chains, the drag reduction ability decreased significantly. The temperature-dependent DR efficiency was also investigated, although the initial percentage DR washighest at a room temperature although, the DR declined most rapidly at high temperature as higher DR efficiency was obtained at a lower temperature than at a higher temperature.

Edomwonyi-Otu (2015, 2019) applied two different molecular weights; 5 x 10^6 g/mol and 8 x 10^6 g/mol polyethylene oxide (PEO) polymers to investigate the effect of molecular weight on drag reduction. From the two types of PEO tested, drag reduction was found to increase with polymer molecular weight but also depended on the mechanical degradation of the polymers at high Reynolds numbers and their ionic strength. He obtained maximum drag reduction of 70% 8PEO and 55% 5PEO for Reynolds numbers over 42000.

The effect of temperature variation on the effectiveness of partially hydrolyzed polyacrylamide in drag reduction was recently investigated (Magit *et al.,* 2019), using 20 mm pipe diameter they observed that in single phase flow, drag reduction decreased from 75% to 62% when temperature was

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raised from 5 to 60ºC, while in multiphase flow, drag reduction decreased from 64.58 to 50%. They concluded that in all cases studied, drag reduction reduced with increase in temperature for partially hydrolyzed polyacrylamide.

Although drag reduction phenomenon has been studied extensively, there is very little information available on the effect of temperature and pipe diameter on drag reduction characteristics of polyethylene oxide. Most of the cited literature tend to focused on large pipes of greater than 20 mm internal diameter while in recent years there is a growing number of papers on liquid-liquid flows in very small pipes driven by process intensification requirements. Also, it was reported (Edomwonyi-Otu and Angeli, 2015) that data on intermediate pipe sizes (10 mm ID to 20 mm ID) are very few in the open literature, hence the need to compare the effect of pipe diameter and temperature on the effectiveness of polyethylene oxide as drag reducing polymer.

Materials and Methods
The polymer used in this work was polyethylene oxide (PEO), molecular weight (8×10^6 g/mol). The polymer was used as received without further purification. 2000 ppm of the polymer was prepared as follows: About 5 g of the polymer was weighed and gently sprinkled into 2.5 liters of water in a vessel. The mixture was stirred. This is to ensureuniform distribution of the polymer particles in the solution, and to avoid forming any lumps. The stirred solution was left for at least 12 h (mostly overnight), before use for proper hydration of the polymer particles. This resulted to a clear solution like water, with no trapped bubbles (Abdallah *et al.,* 2019; Abdullah *et al.,* 2008). The polymer was not soluble in the oil phase and therefore it is expected to remain within the water phase in which it is soluble.A polymer injection pump (New Era Model No.NE-9000); with accuracy of ± 2% was used to inject the polymer into the flow system.

The experimental system consists of two buildup tanks (for water and diesel respectively), with capacity of 200 liters each, and two 1-horsepower surface pumps including 0.02 m ID and 0.012 m ID uPVC pipes. It also has U-tube manometer (Pyrex), flow control valves and two flowmeters (LZM-2); with accuracy of ± 5%, sensors (thermocouple TC35), heater (IH 0509) and temperature controller (RKC-C100). The testing section comprises of 0.02 m ID uPVC pipe. A 1m long acrylic view section with two pressure ports located 0.5 m apart. A U-tube manometer was connected via rubber tubing to the pressure ports. The first pressure port is located 2.5 m from the mixing point, to allow for fully developed turbulent flow before pressure drop readings are taken. The separator, with a capacity of 220 liters, was used to recovered used diesel which was then recycled back to the diesel buildup tank for further use. This separation was enhanced via gravity/density differential between the testing fluids. The U-tube manometer was used to measure the height difference of the two fluids, which was now used to calculate the pressure drop, while the flowmeter was used to regulate the flow rate of fluid passing through pipes. The heater was used to raise temperature to required value while the thermocouple used to

sense temperature variation along with the controller to process the signal sent by the thermocouple and display the set or required temperature.

From each of the storage tanks, a surface pump was used to transport the fluid to the testing section. Each flow line is fitted with a flow meter and a control valve. The flow meters are calibrated. The fluids are brought together via the use of a smooth Y-junction (at an angle of 45º), which minimizes their mixing. 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 into the water phase by using a new Era-programmable peristaltic pump (model NE-9000); with accuracy of ± 2% which was calibrated to give different final polymer concentration in the flow system depending on the water flowrate.

In all tests, the base fluid (water) was first circulated through the straight pipe to calibrate the system. The results were used as the baseline for data analysis. The flow rate was set at a desired value and the steady state pressure drop data were recorded. The flow rate was then increased and the corresponding pressure drop was noted. At each flow rate, about 5 min was allowed for the fluid to achieve steady state conditions.

Plate 1: Photograph of the experimental flow facility

Plate 1, shows the photograph of fabricated rig located at the Multiphase Flow Laboratory in the Department of Chemical Engineering, Ahmadu Bello University Zaria; while Fig. 1 is the schematic diagram of the experimental set-up.
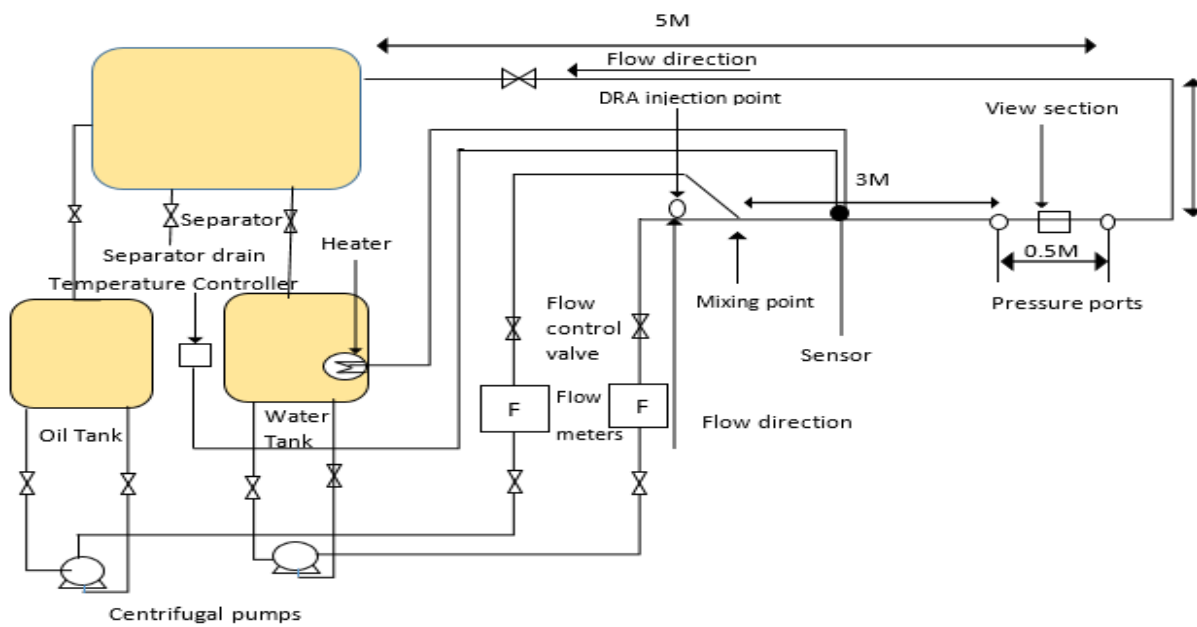
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Fig. 1: Diagram showing the experimental flow facility

Results and Discussion
Drag reduction at room temperature
The experiment was carried out at room temperature and the results for both single and multiphase flow are presented in Figs. 2 and 3, respectively. For all the flowrates studied, percentage of drag reduction increasedwith increase in polymer concentration, but when it reaches a saturation concentration of 30 ppm and fixed flowrate of 30 l/min, there is no more reduction observed. This may be due to the addition of more polymer molecules with increased concentration, which leads to increase in viscosity, and further leads to increased drag reduction (Edomwonyi-Otu *et al.,*

2016; Edomwonyi-Otu and Angeli, 2014; Yusuf *et al.,* 2012). Drag reduction also increases by increasing the transported fluid flow rate represented by Reynolds number (Re) as shown in Fig. 2. This behavior is due to increase in the degree of turbulence that provides a suitable media for the drag reducing agent to act efficiently in media by suppressing the turbulence structures formed. These findings corroborate previous reports (Al-Sarkhi 2010; Al-Sarkhi and Hanratty 2001; Al-Wahaibi, Smith, and Angeli 2007; Dosumu *et al.,* 2019; Edomwonyi-Otu, Chinaud, and Angeli, 2015; Gimba *et al.,* 2019; Mowla and Naderi, 2006).
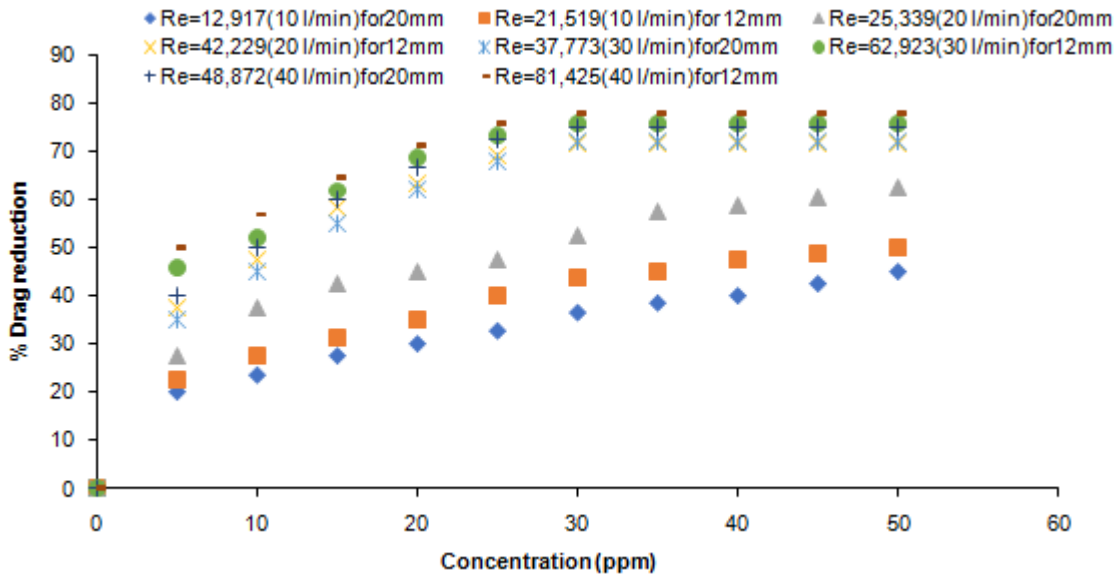

Fig. 2: Effect of concentration and Reynolds number on drag reduction (single phase flow)

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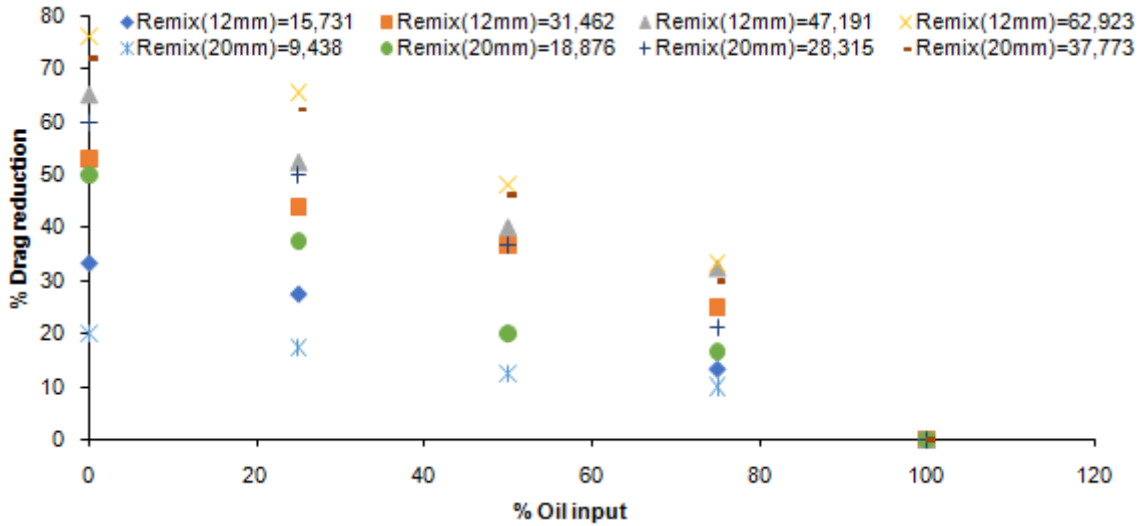
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Fig. 3: Effect of mixture Reynolds number on drag reduction of different oil fraction (Multiphase flow)

In oil-water flows, drag reduction decreased with increased in oil input at fixed mixture Reynolds number till it reaches 100% oil input where insignificant drag reduction was noticed. This is due to the fact that the DRA is only soluble in the water phase and as the oil flowrate increases, it also implies that oil occupies a larger part of the cross section, as such its contribution to the two-phase pressure drop is more important to that of the water phase which leads to reduced water wetted perimeter and less interaction of the polymer with the solvent (Al-Yaari et al., 2009).

Effect of temperature on drag reduction
The effect of temperature on drag reduction was studied in both single and multiphase flows. It was observed that in all cases studied, drag reduction decreased with increased in

temperature from 5 to 60ºC. in single phase flow while a decreased from 80.61 to 60% was observed using 20 mm ID, and 84 to 66.8% using 12 mm ID at a fixed flowrate of 30 l/min as shown in Fig. 4. While in multiphase flow, a decrease from 70.83 to 50% using 20 mm ID, and 73.08 to 54.62% using 12 mm ID at a fixed oil input of 25% was observed as shown in Fig. 5. This decrease was considered to occur due to a reduction in solvation of the polymer molecules as the temperature increased (Magit et al., 2019). It can also be as a result of decreased polymer-solvent interaction which decreases the radius of gyration of the molecule. Therefore, viscosity decreases as temperature increases. As a result, drag reduction decreases which is in agreement with a previous report (Magit et al., 2019; Yusuf et al., 2012).
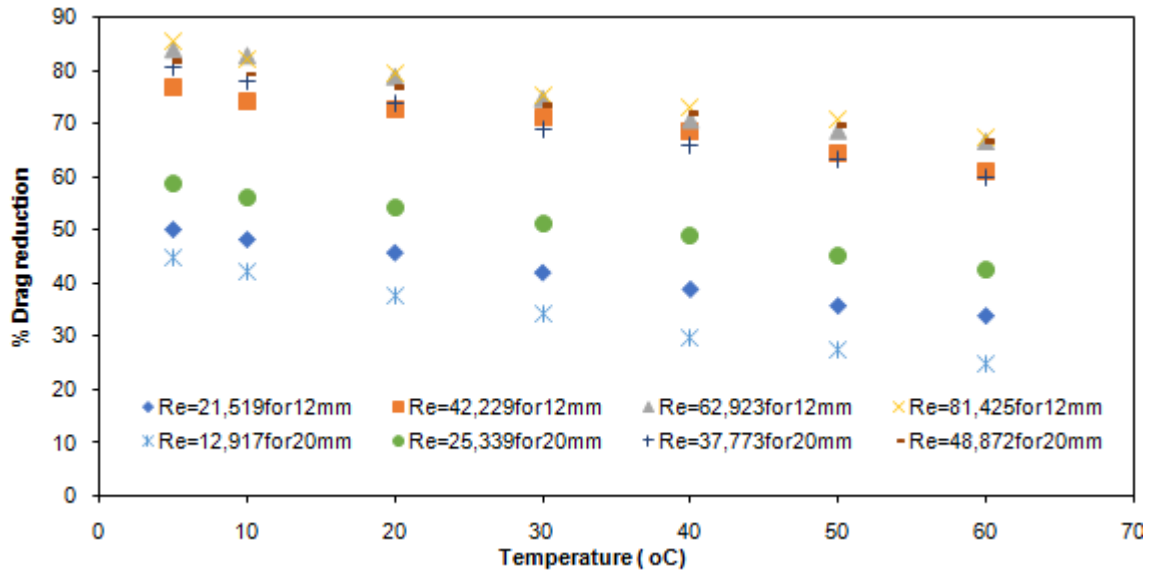

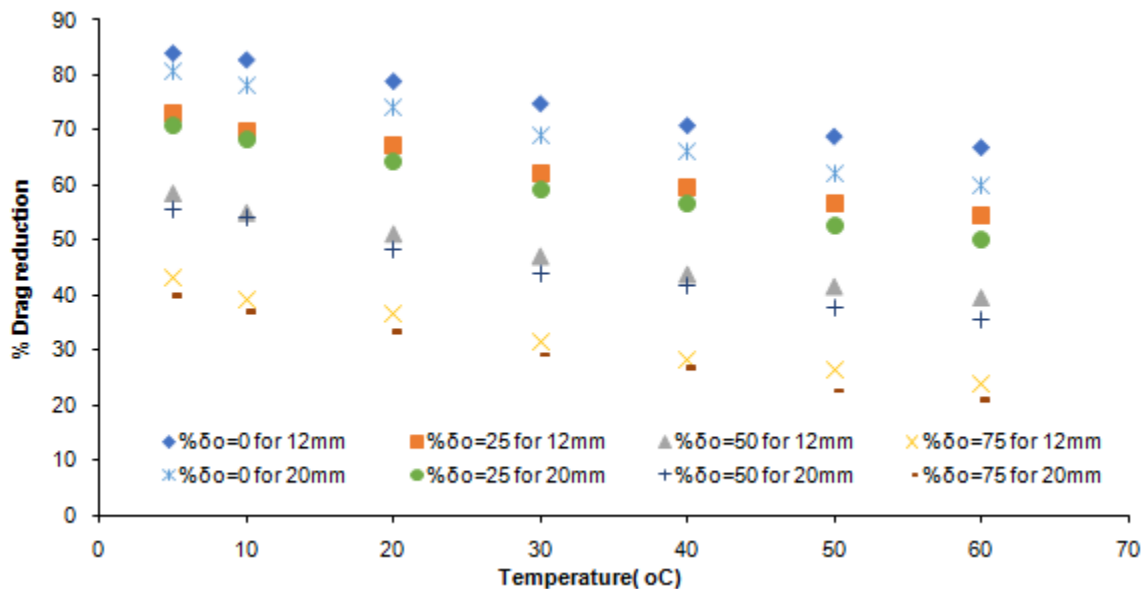**Fig. 4: Effect of temperature on drag reduction for 12 and 20 mm ID (Single phase flow)**

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Fig. 5: Effect of temperature on drag reduction at different oil input for 12 mm/20 mm ID (Multiphase flow)

Effect of pipe diameter on drag reduction in single and multiphase flow

The effect of pipe diameter was studied at room temperature and also varying temperature. For the room temperature in Figs. 2 and 3, drag reduction was seen to be high using the smaller pipe diameter than the larger pipe diameter. Drag reduction of 76% was observed for 12 mm ID, while 72% was observed for 20 mm ID at a fixed flowrate of 30 l/min in single phase flow. In multiphase flow, drag reduction of 65.25% was observed for 12 mm ID and 62.25% for 20 mm ID at a fixed oil-input of 25%. This observation was as a result that decreasing the pipe diameter means increasing the velocity inside the pipe and by that, the turbulence will increase (Edomwonyi-Otu *et al.,* 2016; Gimba *et al.,* 2019; Yusuf *et al.,* 2011). Although, the flow is turbulent but the degree of turbulence is different. For smaller pipe, the energy absorbed by eddies in turbulence mode from the main flow will be higher than the energy that absorbed for larger pipes. By these phenomena, when the degree of turbulence become higher, the number of collisions between eddied will increase and produce smaller eddies. These collisions provide extra number of eddies to absorb energy from the flow to complete their shape. Overcoming smaller eddies is easier than larger once, this is because of the amount of energy absorbed by smaller eddies is lower (Magit *et al.,* 2019).

However, comparing the effect of temperature and pipe diameter, it was observed that in single phase, drag reduction decreased from (80.61% to 60%) 20 mm ID, (84% to 66.8%) 12 mm ID while in multiphase flow a decreased from (73.83% to 50%) 20 mm ID, (73.08% to 54.62%) 12 mm ID with increased in temperature from 5 ^{0}C to 60 ^{0}C.

Conclusion

The addition of 30 ppm of PEO causes about 72 and 76% drag reduction using both 20 mm and 12 mm pipe diameter, respectively at a fixed flow rate of 30 liters/min and single-phase flow. While in multiphase flow, drag reduction of 62.25 and 65.25% was observed for 20 mm and 12 mm pipe

diameter respectively at a fixed oil-input of 25%. In all cases studied, drag reduction decreased with increased in temperature from 5 to 60°C, but the decreased is slightly higher in larger pipe diameter compared to the smaller one.

Conflict of Interest
Authors have declared that there is no conflict of interest reported in this work

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