



Original Research Article

Effect of Temperature Variation on the Effectiveness of Partially Hydrolyzed Polyacrylamide in Drag Reduction

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ARTICLE INFORMATION

Article history:

Received 19 August, 2018

Revised 27 February, 2019

Accepted 02 March, 2019

Available online 30 Dec, 2019

Keywords:

Drag reduction

Turbulence

Temperature

Efficiency

Temperature

ABSTRACT

The addition of certain heavy molecular weight polymers to flowing fluids has been known to reduce drag thereby increasing the efficiency of the system. Temperature is one of the factors that can affect the extent of drag reduction. This study is focused on the effect of temperature on the effectiveness of partially hydrolyzed polyacrylamide (HPAM) as drag reducing agent. The flow facility is made from unplasticized polyvinyl chloride (uPVC) pipe of 20 mm internal diameter (ID). Temperature range of 5 °C to 60 °C, polymer concentration of 5 ppm to 50 ppm and Reynolds numbers less than 100000 were studied using oil [diesel] (density = 832 kg/m³, viscosity = 1.664 mPa.s at 25 °C) and water (density = 1000 kg/m³, viscosity = 0.91 mPa.s at 25 °C) as test fluids. Pressure drop was measured using a U-tube manometer. The results showed that in single phase (water) flow, a maximum drag reduction of 70% was achieved in horizontal flow at room temperature. Drag reduction decreased from 75% to 62% when temperature was raised from 5 °C to 60 °C. In multiphase flow, a maximum drag reduction of 58.33% (25% oil input, $U_{mix}=1.68$ m/s, room temperature) was observed. Similarly, as temperature increased from 5 °C to 60 °C, drag reduction decreased from 64.58% to 50%. In all cases studied, drag reduction reduced with increase in temperature for partially hydrolyzed polyacrylamide.

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1. INTRODUCTION

Multiphase flow is a common occurrence in the petroleum industry, where oil and water are often transported together through pipelines of varying size (Edomwonyi-Otu and Angeli, 2014, 2015). These fluids are transported in turbulent mode and they experience drag. Pumps are installed to sustain the flow but this leads to increased utility costs for both installation and maintenance. The addition of certain heavy molecular

weight polymers to flowing fluid has been known to reduce the drag thereby increasing the efficiency of the system (Gimba et al., 2017; Gimba et al., 2018).

Drag reduction can be defined as an engineering intervention whereby small amounts of additives, for instance a few parts per million (ppm), added to flowing fluids, leads to reduction of the turbulent frictional drag (Edomwonyi-Otu et al., 2014). The main objective of drag reduction is to enhance the fluid mechanical efficiency using active agents that is known as drag reducing agent (DRA). In single and multiphase flow, drag reduction (DR) can be defined as the ratio of reduction in the frictional pressure difference with DRAs when the flow rates are held constant, to the frictional pressure difference without DRA, and then multiplied by 100, as shown in Equation (1).

$$\% DR = [(\Delta P_b - \Delta P_a) / \Delta P_b] \times 100 \quad (1)$$

where ΔP_b is the frictional pressure difference before adding the additives, N/m^2 and ΔP_a is the frictional pressure difference after adding additives, N/m^2 .

Polymers, surfactants and fibers are known to lower the friction pressure losses up to 80 percent over the solvent (Edomwonyi-Otu et al., 2016). Numerous studies (Lumley, 1969; Virk, 1975; Berman, 1978; Hoyt, 1985; Edomwonyi-Otu et al., 2015) provide extensive reviews on this topic.

The following factors have been known to affect the effectiveness of polymers in drag reduction. They include method of addition and injection into flowing fluid, nature of mixing point in multiphase flow systems (homogenous or heterogeneous addition), concentration of master solution, pipe diameter and inclination, pipe roughness, temperature and pH, presence of turbulent flow, fluid viscosity (including its hydrodynamic viscosity), presence of paraffin and or saline water and pipe length (Edomwonyi-Otu et al., 2015).

Drag reduction in oil-water flow was first reported by Al-Wahaibi et al. (2007), where a 14 mm ID acrylic pipe was used. A co-polymer (Magnafloc 1011; of polyacrylamide and sodium acrylate) solution in water and oil (viscosity; 5.5 mPa.s, density; 828 kg/m^3) was used as the test fluid. They used 20-50 ppm concentrations from 1000 ppm master solution and with the aid of the two-fluid model they noted a decrease in both the interfacial and water wall shear stresses when the polymer was added.

Abid-Ali and Al-Ausi (2008), studied the effect of temperature variation of polyisobutylene in single phase flow using a 1.25-in. ID within the temperature range of 30–50 °C. The result showed that drag reduction increased with increase in temperature up to 45 °C where a maximum of 33% was achieved. They recommended that more research should be done on effect of temperature variation because it was not possible to ascertain whether the same trend of temperature was true for all investigations as the published works on these parameters are very limited. Yusuf et al. (2012) carried out their experiment with oil–water flow in a horizontal 25.4 mm ID acrylic pipe using high molecular weight (HMW) anionic co-polymer of 40:60 wt and wt NaAMPS or acrylamide as a drag reducing polymer (DRP), The results showed that as low as 2 ppm polymer concentration was enough to create a significant drag reduction across the pipe. DR increased with polymer concentration and reached maximum at 10 ppm. They observed a maximum DR of about 60% oil superficial velocity (U_{so}) of 0.14 m/s and 0.52 m/s. Al-Wahaibi et al., (2013) studied the effect of drag reducing polymers using two pipe diameters of 19 mm ID and 25.4 mm ID in an oil-water flow. They reported maximum drag reduction of 45% for 19 mm ID and 60% for 25.4 mm ID.

Edomwonyi-Otu, (2015) used oil-water mixture in a horizontal 14 mm ID acrylic test section using (Magnafloc 1011; hydrolysed copolymer of polyacrylamide and sodium acrylate, HPAM, mol. wt. = 10×10^6 g/mol) as drag reducing polymer and the test fluids were a distillate oil (Exxsol D140: viscosity 5.5 mPas, density 828 kg/m^3) and tap water. He noted that adding 20 ppm of polymer solution to the water phase

resulted in drag reduction of 80 % in single phase water flows and 52 % in oil-water flows. Recently, Edomwonyi-Otu and Adalakun (2018) reported that the heavy molecular weight polymers could be used for the transportation of drinking water from treatment plants to consumption points.

Although drag reduction phenomenon using partially hydrolyzed polyacrylamide has been studied extensively, there is very little information available on the effect of temperature on its drag reduction characteristics in oil-water flows. The present study is thus focused on the effect of temperature on the effectiveness of partially hydrolyzed polyacrylamide (HPAM).

2. MATERIALS AND METHOD

2.1. Materials

The polymer used in this work was Magnafloc 1011, a partially hydrolyzed polyacrylamide (HPAM) of molecular weight (10×10^6 g/mol). The polymer was used as received without further purification. The 2000 ppm of the polymer solution was prepared as follows:

Five grams (5 g) of the polymer was weighed and gently sprinkled into 2.5 liters of water in a vessel. The mixture was stirred to ensure uniform distribution of the polymer particles in the solution, and to avoid forming any lumps. The stirred solution was left for at least 12 hours (mostly overnight), before used for proper hydration of the polymer particles. This resulted in a clear solution like water, with no trapped bubbles seen (Edomwonyi-Otu, 2015). The polymer was not soluble in the oil phase and therefore it was expected to remain within the water phase in which it was soluble. A polymer injection pump (New Era Model No. NE-9000), with accuracy of $\pm 2\%$ was used to inject the polymer into the flow system.

2.2. Methods

The experimental system consisted of two buildup tanks (for water and diesel respectively), with capacity of 200 liters each, two 1 horsepower surface pumps, 0.02 m ID uPVC pipe, U-tube manometer (Pyrex), flow control valves and two flowmeters (LZM-2); with accuracy of $\pm 5\%$, sensors (thermocouple TC35), heater (IH 0509) and temperature controller (RKC-C100). The testing section comprises of 0.02 m ID uPVC pipe. Acrylic pipe of 1 m long with two pressure ports located 0.5 m apart was used as the viewing section. U-tube manometer (Pyrex) connected via rubber tubing to the pressure ports which was used measuring the pressure drop. The first pressure port was located 2.3 m from the mixing point, to allow for fully developed turbulent flow before pressure drop readings were taken. The separator, with a capacity of 220 liters, was used to recover used diesel which was then recycled back to the diesel buildup tank for further use. This separation was done using the differences in density between the testing fluids.

The U-tube manometer was used to measure the height difference of the two fluids, which was then 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 the required level, and thermocouple was used to sense temperature variation. The controller was used to process the signal sensed by 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 was fitted with a calibrated flow meter and a control valve. 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 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 $\pm 2\%$ which was calibrated to give different final polymer concentration in the flow system depending on the water flowrate.

In all the 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, adequate time was allowed for the fluid to achieve steady state conditions. Solutions of HPAM (5-50 ppm) were prepared and tested for apparent viscosity measurement at varying temperature of 5-60 °C using Fann viscometer (35A) with accuracy of $\pm 1\%$.

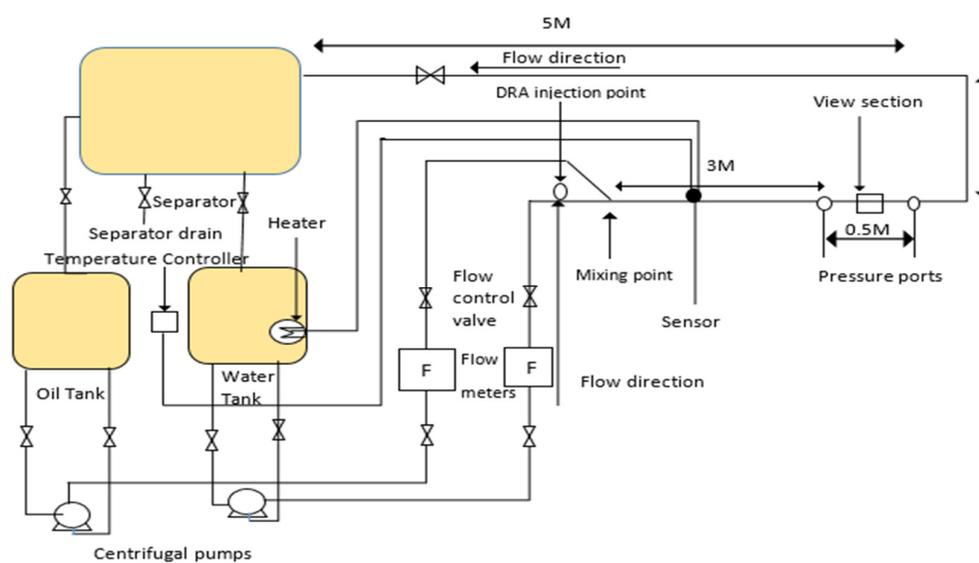


Figure 1: Diagram showing the experimental flow facility

3. RESULTS AND DISCUSSION

3.1. Viscosity Test Results

The apparent viscosity of HPAM at concentrations of 5-50 ppm and varying temperature are presented in Figure 2.

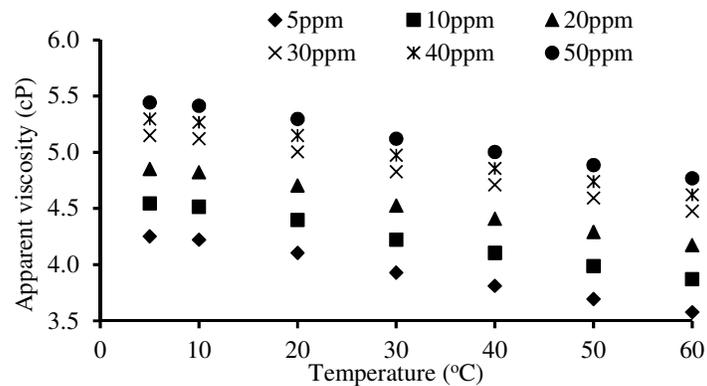


Figure 2: Effect of temperature on apparent viscosity of HPAM of different concentrations

It was observed from Figure 2 that apparent viscosity increased from 4 cP to 5.2 cP (HPAM) as the DRA concentration was increased from 5 ppm to 50 ppm. This can be attributed to the polymeric nature of highly molecular weight DRA which participates in increasing viscosity (Zeynali et al., 2004). The apparent viscosity decreased from 5.1 cP to 4.5 cP (HPAM) as temperature increased from 5 °C to 60 °C at 30 ppm, which is due to the deterioration of the polymer-solvent interaction that lead to decrease in the radius of gyration of the molecule and consequently a decrease in viscosity (Dey and Laik, 1986; Choi et al., 2000).

3.2. Single Phase Flow Results

The experiment was first carried out in single phase and at room temperature to determine the suitable conditions to be used in subsequent experiment. The results are presented in Figure 3.

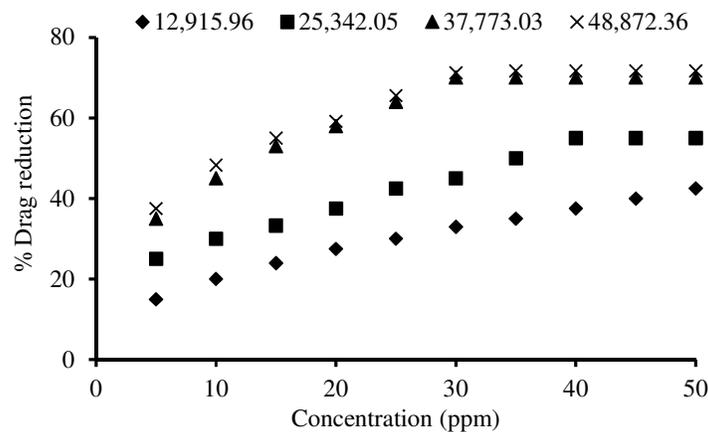


Figure 3: Effect of Concentration and Reynolds number on drag reduction of HPAM

Drag reduction increased with increase in polymer concentration at different Re as shown in Figure 3. It reaches a saturation concentration of 30 ppm at Reynolds number of 37,773 beyond which insignificant DR was observed. This behavior was due to the increased degree of turbulence that provides a suitable media for the drag reducing agent to act efficiently in the media by suppressing the turbulence structures formed (Edomwonyi-Otu and Angeli 2019; Edomwonyi-Otu et al., 2015; Gimba et al., 2018). Increasing the degree of turbulence relates to increasing the number of eddies that absorb the energy from the main flow to complete its shape. It can also be observed that drag reduction increased with fluid flow rate represented by Reynolds number (Re) as shown in Figure 3. Drag reduction continues to increase even at higher Reynolds number which was due to higher stretching of the polymer chains which dampens the turbulence more effectively (Edomwonyi-Otu and Angeli, 2019; Abubakar et al., 2014). The polymer concentration at which maximum drag reductions were achieved in this study is different from 10 ppm and 20 ppm obtained by Yusuf et al., (2012) and Edomwonyi-Otu (2015) respectively. However, the trend of sharp increase in the drag reduction at low polymer concentrations before the increase became gradual and agrees with their previous findings.

3.3. Effect of Temperature in Single Phase

The effect of temperature was studied in single phase and results were presented in Figure 4. It was observed that as temperature increased from 5-60 °C, drag reduction decreased from 75% to 62% at 37,773 Reynolds number. It may be ascribed to the deterioration of the water-polymer interaction, diminishing of the macromolecules size, decreasing the hydrodynamic radius of the molecules, and changes in the conformational state of the polymer (Clifford and Sorbie, 1985; Nesyn et al., 1989).

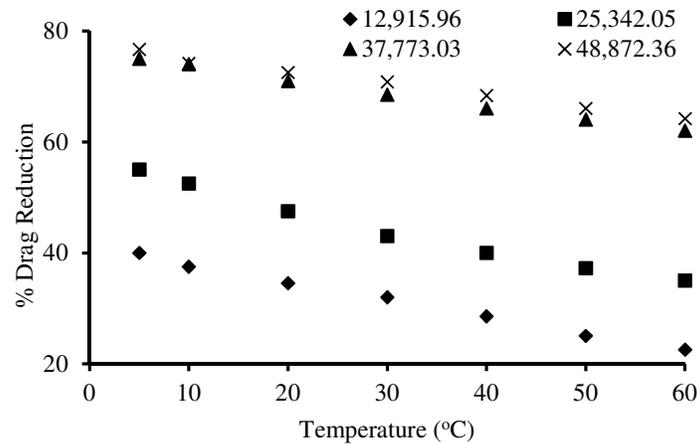


Figure 4: Effect of temperature on drag reduction of HPAM in single phase flow

Water is known to be a good solvent but its power is drastically decreased by increasing temperature due to a decrease in hydrogen bonding ability (Kamel and Shah, 2009). This reduces the interactions between the polymer and the bulk solvent which translates to a decrease in drag reduction. Another consequence of decreased polymer-solvent interaction is the decrease in the radius of gyration of the molecule. Therefore, intrinsic viscosity decreases as temperature increases. As a result, drag reduction decreases (Dey and Laik, 1986; Choi et al., 2000). Similar trends were observed for all the flowrates represented by Reynolds number. This trend agrees with the findings of Interthal and Wilski (1985). They noted a decrease in DR from 70 to 50% as temperature was increased from 5 °C to 35 °C in single phase with 14 mm ID pipe. Kamel and Shah (2009) also observed that DR decreased from 76% to 64% as temperature increased from 22 °C to 55 °C.

3.4. Multiphase Flow Results

Experiments were carried out for horizontal oil-water flows. Pressure drop in oil-water flows were measured with and without DRA for each of the DRA. The concentration and flow rate at which the optimal DR was achieved in single phase was selected. The velocity at that particular flow rate was taken as the mixture velocity (U_{mix}) of the test fluids (Abubakar et al., 2016). Mixture Reynolds number was calculated from each of the mixture velocity, and oil input were varied from 0 to 100%.

Figure 5 shows the effect of mixture Reynolds number Re_{mix} on the percentage drag reduction (%DR) of HPAM in multiphase flow at room temperature. The results show that drag reduction increased from 17.5 to 70% with increasing mixture Reynolds number of 9,438 to 37,773 for 0% oil input. Since velocity is proportional to Reynolds number, it implies that increasing the Reynolds number results in higher turbulence, providing better media for better drag reduction effectiveness. The results corroborate the report by Abubakar (2016). It can also be seen that drag reduction is most effective in the pure water phase ($\delta_o = 0$). Subsequently, as the diesel is added, the percentage drag reduction reduces continuously until it disappears in the pure diesel phase ($\delta_o = 100$). This is in agreement with the findings of Edomwonyi-Otu (2015) and Abubakar (2016). They noted that drag reduction with water-soluble DRA in oil-water flows is inversely proportional to the oil input fraction. This is due to the fact that drag reduction only takes place in the water phase since the DRA is only soluble in that phase.

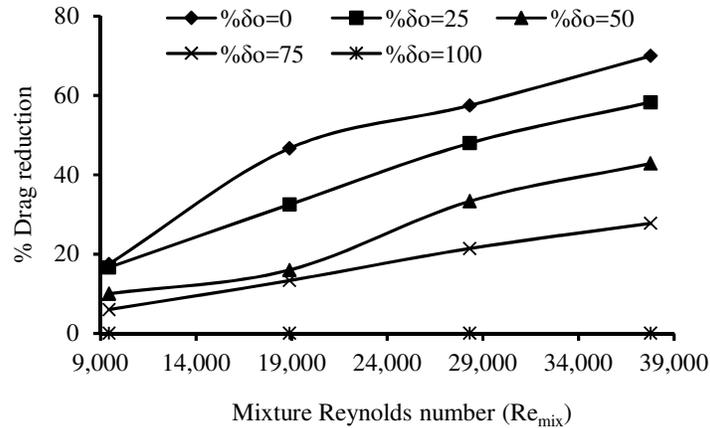


Figure 5: Effect of Mixture Reynolds number on drag reduction of in oil-water flows

3.5. Effect of Temperature in Oil-Water Flows

Figure 6 shows the effect of temperature in multiphase flow at oil input ranging from 0 to 100%. Similar trend was observed as that of single phase flow. As the oil input increased from 0 to 100 %, there was a decrease in drag reduction from 75% to 0%. This is because larger part of the pipe cross section was occupied by the oil as a result of increase in oil flowrate, as such its contribution to the two-phase pressure drop is more important than that of the water phase particularly at low water rates because the water wetted perimeter is reduced and the DRA was only soluble in water phase as such the presence of oil tends to reduce the effectiveness of the DRA (Edomwonyi-Otu et al. 2015).

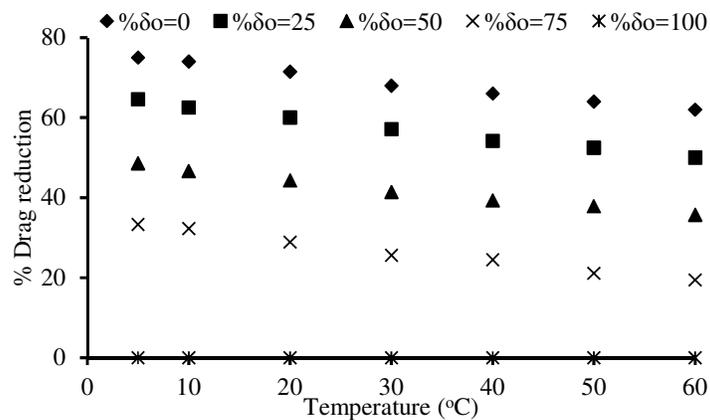


Figure 6: Effect of temperature on drag reduction of HPAM in oil-water flows

4. CONCLUSION

Experiments were carried out to investigate the effect of temperature variation on the effectiveness of partially hydrolyzed polyacrylamide in oil-water flows. Maximum drag reduction of 75% was observed at low temperature of 5 °C, while drag reduction decreased to 62% at higher temperature of 60 °C in single phase flow. Addition of the DRA only affected the water-dominated flow regions in multiphase flows. Drag

reduction of 64.58% was observed at low temperature in multiphase flows (Oil input (δo) =25%) and it reduced to 50% for higher temperature at same oil input of 25%. In all cases studied using partially hydrolyzed polyacrylamide, drag reduction reduced with increase in temperature.

5. ACKNOWLEDGMENT

The authors wish to acknowledge the technical and financial support of the members of the Multiphase Flow and Separation Systems Research Group of the Department of Chemical Engineering, Ahmadu Bello University Zaria, Nigeria.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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