IMPROVEMENT OF SHARARA CRUDE OIL FLOW USING POLYSTYRENE AND POLYDIMETHYLSILOXANE AS DRAG REDUCING AGENTS

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Abstract

In this study the applicability of the Libyan crude oil flow induced by improved lab pumping system was examined in order to evaluate the effect of adding polymeric materials of Polystyrene and Polydimethylsiloxane as drag reducing agents (DRA) on the flow of Sharara crude oil in the pipeline. The polymers are injected through a pumping system at different concentrations rounded between (10-100) ppm. Several experiments were carried out to determine the best concentration of polymer, which satisfied lowest drag force on of crude oil flow rate. Furthermore, the effect of additive concentration on the Viscosity(μ), friction factor (f), percentage drag reduction (%DR) and the amount of flow increases (%FI) were determined. The results show that the activities of Polydimethylsiloxane for Drag reduction is higher than drag reduction for Polystyrene. However, the %DR is generally increased with increasing of polymer concentration for all tested additives. It is progressively increased with increasing Reynolds number (Re) at any specific concentration of the polymeric additives. The friction factor is well correlated with Reynolds numbers and polymer concentration according to the relation of the form $f = k\, Re^a C^b$, the results showed good agreement between the observed values and the predicted ones.

Keywords: Crude oil, polymer, drag reduction, turbulent Flow, pipeline.

Introduction

Transportation of Liquid occurs in many chemical and process industries including the petroleum industry, where crude oil and its derivatives are transported over long distances trough pipelines. Friction experienced by oil flowing past the pipe walls leads to a pressure drop between two points on the pipe by Murenzi, D. (2008). Addition of specific material such as sand, and mud can result in reduction of friction in turbulent pipe flow, which has been known for over fifty years, and the added material is called drag reduction agent (DRA) by Toms, B. (1948). This technique is important from scientific and economic point of view and this is achieved by injecting traces of drag reduction materials with crude oil in the turbulent flow condition, which helpful leads to pump crude oil for long distances without losses in the pressure, such as pumping system in the refining for purification to its components or transport to harbors for export. Furthermore, nowadays synthetic materials such as polymers, surfactants, fibers, and nano-materials being investigated to be used as drag reducing additives in chemical and petroleum industries by Li, C. et al (2006), Cho, S. et al (2007), Peet, Y. et al (2008), and Ruiz-Viera, M. et al (2006).

During the past decade, different type of polymers has been investigated in order to be used for increasing of pumping efficiency of crude oil through transportation pipe by mechanism of drag reduction by Kai, Y. et al (2018), Wiely, J. (1979), Motier, J. (1984), Qaiser, M. et al (2008), Baranov, V. (2001), Lester, C. (1985), and Martınez -Palou, R. et al. (2011). Polymers have several unique properties such as high molecular weight and entanglements molecules, which believed to have large effect on the drag reduction (DR) by Weicong, H. (2015), Taylor, F. (2006), and Marcel, D. (1999). Furthermore, one of the most important factors that affect the flow is the flowing fluid properties Therefore properties of crude oil, have very important role on pumping efficiency.

Although a large number of researches have been conducted to study the drag reduction effect (DRE) of various additives on low API crude oil, the literature about the drag reduction effect of additives on medium to high API crude oils is very limited by Beaty, W. (1984). Therefore, Sharara crude oil is chosen in this work to be investigated into the drag reduction effect of two different polymeric materials, with various concentrations. The polymers that will be used are polystyrene (PS) and polydimethylsiloxane (PDMS).

The transfer of crude oil throughout pipeline technology is most often utilized. However, the flow in most practical applications is turbulent. Turbulent flow results in a lot of energy loss due to the turbulent dissipation of energy that results from friction. Therefore, study the effect of additive materials on the drag forces for flowing crude oil is quite helpful to oil transportation industries. In order to increase the Libyan crude oil export, Sharara crude oil was used in this study, such study that is expected to increase the flow rate and thus pumping efficiency of the crude oil. Originally from the Toms phenomena, he said that the addition of even very small (5 ppm) of polymeric material can cause the reduction of turbulent drag by 80% in fully developed boundary layer and channel flows by Toms, B. (1948). It was showed that the presence of turbulence can be reduced with the addition of small amount of polymer.

Drag reduction is an alternative way to reduce pumping power losses during transportation through pipelines. By injecting the drag reduction agent into a pipeline, the friction pressure losses in a pipeline would be decreased. The significance of this study was to discover a new scheme to reduce the turbulent drag, which is the main step to the pumping power saving and ultimately lead to cost saving with minimum investment. Furthermore, power saving is very essential to the cost saving in the plants.

The goal of the present work was to investigate the validity of the effectiveness of PS and PDMS (concentrations of 10, 20, 30, 40, 50, 60 and 100ppm) as drag reducing agents with Sharara crude oil. The effect of additives concentration on several parameters that have the most significant effect on the flow of fluids were studied; namely the percentage Drag Reduction(%DR), flow rate, viscosity, friction factor, and the percentage flow increases (%FI).

Experimental Work

Materials

The physical properties of this crude oil were provided by industrial laboratories and production technologies department at Zawia refinery plant in Libyan and are shown in the following table.

Table (1): The physical properties of Sharara crude oil.

Physical properties	Value
Kinematic viscosity(υ) at 100°F (cSt),	2.2886
specific gravity	0.8146
API	42.2

Polymers

In the present work, two types of polymer (polystyrene)and(polydimethylsiloxane) were used as a drag reduction agents (DRA) with polymer solution concentrations of 10, 20, 30, 40, 50,60 and100ppm. Their specifications are shown in table (2).

Table (2): Specification of polymers.

Polymers	Scientific name	Chemical structure	Average Molecular weight ($\overline{M}v$)
PS	Polystyrene	$[-CH-CH_2-]_n|C_6H_5$	9×10^4
PDMS	Polydimethylsiloxane	$-[(CH_3)_2Si-O-]_n$	1×10^5

Preparation of Polymer Solution

Polymers are weighted by a sensitive balance, and dissolved in Gasoline to obtain 10% (wt%) concentration in a separate container. Where 10,20, 30,40, 50,60 and 100 ppm polymer concentration obtained from the main solution (10%) at addition to crude oil.

Circulating flow loop system (pumping system rig)

The laboratory of pumping system scheme is described in figure (1), which operates at different conditions of temperature pressure, flow rate and concentration of polymer. The system consists of reservoir tank of solution (20 Liter volume), centrifugal pumps (power =1hp) which used to circulate the solution from the reservoir tank through pipe, flow meter (24 l/min maximum flow rate), valves to control the amount and direction of solution flow rate through the system, and pressure gauges. The pipe length with elbows are about 4.750 m (187.0 inch) with internal diameter is 0.01576 m (0.5 inch). the pipe is made of commercial carbon steel with roughness of 0.0018 to 0.055 by Brill, J. and Beggs, H. (1989).

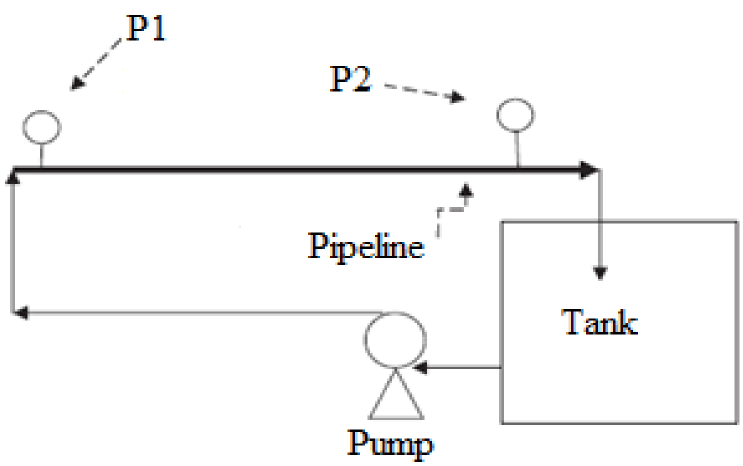

Figure (1): Schematic of flow system.

Drag Reduction Experiment

The preparation of additive solution (PS or PDMS) by mixing small amount of polymer with solvent (Gasoline) is the first step in the experimental procedure, then the solution is added into the reservoir tank of crude oil and used in the recirculation closed system. The flow operation starts by pumping the solution through the testing section for the same pipe diameter and additive concentration. For each run the flow rate of solution was controlled by pass section to a certain value, while pressure drop readings were taken. Readings of pressure drop were taken again when the flow rate of solution was changed to another fixed value. Crude oil without polymers: After switch on the pump, the valve is fixed at a certain flow rate of 16 l/min. The flow rate is read by the device (flow meter) using a stopwatch to calculate how many liters it takes for a given time per second and after which the exit pressure of pump (initial pressure) P_1 and access pressure the reservoir (final pressure) P_2 are taken. In the light of these readings, the flow rate (Q), Reynolds number (Re), pressure drop (ΔP_b) and friction factor (f) are calculated. The same steps were repeated at both the flow rate (18, 24) l/min and for each additive concentrations. The percentage drag reduction (%DR) and percentage flow increase (%FI) were calculated.

Calculations

Two types of polymer (PS and PDMS) was used as drag reducing agents with Libyan crude oil (Sharara crude oil). The following equations were used to calculate the Reynolds number (Re), percentage drag reduction (%DR), percentage flow increase (%FI), and friction factor in terms of fanning friction factor (ƒ) by Ashrafizadeh, S. et al (2012), Manfred, B. et al (1982) and Darby, R. (2001).

$$Re = (\rho \times u \times D)/\mu \quad (1)$$

$$\%DR = [(\Delta P_b - \Delta P_a)/\Delta P_b] \times 100 \quad (2)$$

$$\%FI = ((1/(1 - DR))^{0.55} - 1) \times 100 \quad (3)$$

$$f = [(\Delta p \times D)/(2 \times \rho \times L \times u^2)] \quad (4)$$

Where: D is internal diameter of the pipe in (m), ρ is the density of the fluid in (kg/m^3), u is the average velocity (m/s), Q is the flow rate (m^3/sec), μ is the dynamic viscosity of the fluid (kg/m·s), ΔP_b and ΔP_a pressure drop before and after addition of polymer (bar), L is the pipe length (m).

Results and Discussion

Effect of Polymer Concentration on the Drag Reduction

Figures (2) and (3) shows the effect of polymer concentration on drag reduction process at different concentration. The figures show that the percentage drag reduction (%DR) increases with increasing polymer concentration. The increase in percentage drag reductionis ascribed to increases of associated additive molecules in the process of drag reduction. The relations were increased linearly and then become stable, these results indicate that increasing the additive concentration means increasing the turbulence spectrum that is under the drag reducer effect. This may be due to the increase in the number of polymeric molecules that influences the strength of the degree of turbulence which will lead to the increase in the drag reduction efficiency. The general shapes of these figures are similar to those observed by Kim, H. et al (1971) and Kim, C. et al (2001).

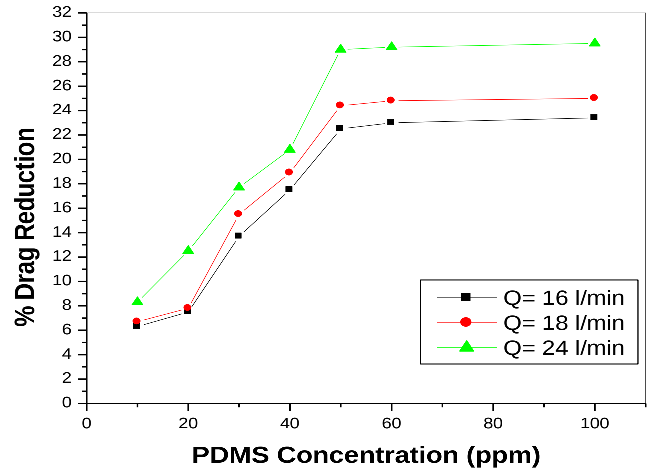

Figure (2): Effect of PDMS concentration on the drag reduction of Sharara crude oil.

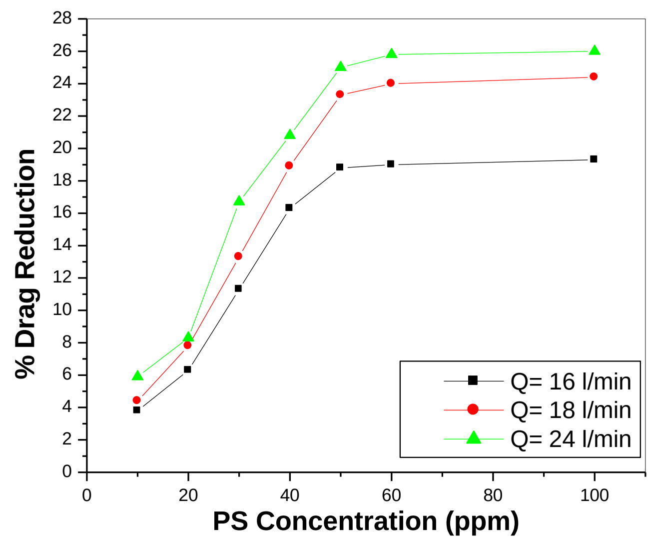

Figure (3): Effect of PS concentration on the drag reduction of Sharara crude oil.

Effect of flow rate on drag reduction

Figures (4) and (5) shows the effect of solution velocity (u) on the drag reduction percentage (%DR) in terms of volumetric flow rate (Q). Different patterns can be observed depending on the factors that were tested in the experiments additive concentration. In most cases, the percentagedrag reduction increases with increasing flow rate until a certain value is reached. The results show that the percentage drag reduction increases with increasing fluid velocity. Increasing the fluid velocity means increasing the degree of turbulence inside the pipe. As the number of collisions between eddies is also increases, smaller eddies are obtained. It is easier to suppress smaller eddies with polymer additives than large eddies as the amount of energy absorbed by smaller eddies is lower. The trade off in %DR after it has reached a maximum value is due to allow ratio between additive concentration and degree of turbulence. similar results were obtained by Kim, N. et al (2000).

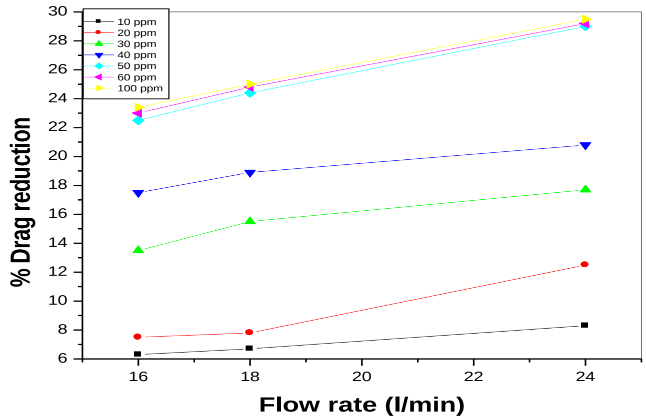

Figure (4): Effect of flow rate on drag reduction for different PDMS concentration of Sharara crude oil.

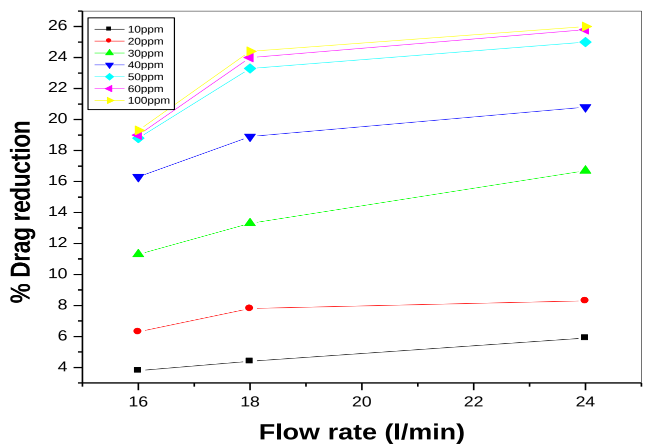

Figure (5): Effect of flow rate on drag reduction for different PS concentration of Sharara crude oil.

Effect of Polymer Concentration on the Viscosity

The relationship between the concentration and viscosity are represented in figure (6). In order to check that the additives PS and PDMS concentration do not affect the physical properties of used crude oil, the viscosity of crude oil was evaluated, the results indicate that there is no change in physical properties after addition as shown in figures. These results agree with the work by Mowla, D. (2006). Moreover, the apparent viscosities of drag reducing solutions change with concentration. Viscosity does not directly predict the drag reduction ability. It can help in the characterization of the solution. The concentration of the polymer PS and PDMS in a drag reduction solution is usually low and viscosity measurements of such solutions are often problematic because of the limited sensitivity of most viscometers. However, the drag reduction increases with an increase in the concentration due to the decreased viscosity of solutions as observed by Kim, C. et al (2001), Kim, N. et al (2000), Mowla, D. (2006) and Virk, P. (1967).

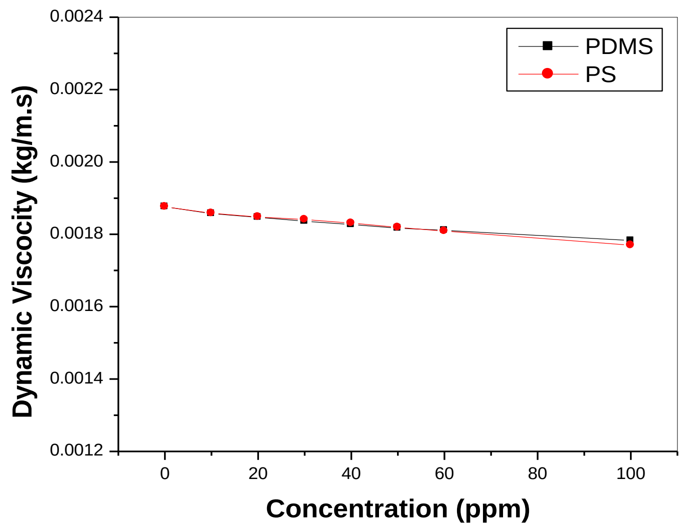

Figure (6): Effect of polymer concentration on the viscosity of Sharara crude oil.

Effect of Polymer Concentration on the Friction Factor

Figures (7) and (8) show that the friction factor various Reynolds number for Sharara crude oil with PDMS and PS solutions, respectively. These figures showed that the friction factor decreased with increasing fluid velocity in terms of the dimensionless group (Re). The fiction factor (f) achieved with the turbulent flow of Newtonian fluids in smooth cylindrical pipes and tubes is related to Reynolds number (Re) by the well known Blasius equation by Ashrafizadeh, S. et al (2012).

$$f = 0.0791\ Re^{-0.25} \quad (5)$$

Virk et al. suggested a unique asymptote for expressing the relationship between (f) and (Re) at the maximum drag reduction by dilute polymer solutions in turbulent pipe flow according to the following relation:

$$f = 0.59\ Re^{-0.58} \quad (6)$$

In the laminar flow where the friction factor follows poisuells law at which the following equation is used by Ashrafizadeh, S. et al (2012):

$$f = 16\ Re^{-1} \qquad (7)$$

Figures (7) and (8) also show the effect of Reynolds number on friction factor for different concentrations of polymers. It is noticed that friction factor decreases with increase in Reynolds number for newtonian fluid flow, also increase in concentration causes decrease in friction factor due to slide of layers near the wall on each other. it can be noticed that the some of experimental data points are located near to Blasius asymptote when the solvent was pure (without polymer), also after the addition of additive PS and PDMS. While the data points positioned toward Virk asymptote need to increasing concentration and the maximum limits of drag reduction as shown in figures. It was difficult to reach these limits of lowering resistance because of the higher concentration of additives is required to achieve this condition. Moreover, the figures indicate that the data points of crude oil obey Blasius equation, while the data points of polymer solutions are progressively shifted in the direction of Virk asymptote with increasing concentration. However, the general shapes of Figures are entirely similar to those observed by other workers regardless of the types of polymers or solvents. The resultsobserved by Abdul Bari et al. (2008) for sodium stearate surfactant (SS) dissolved in kerosene. Possibility of degradation of polymers is not exists according to reference Kim, C. et al (2000).

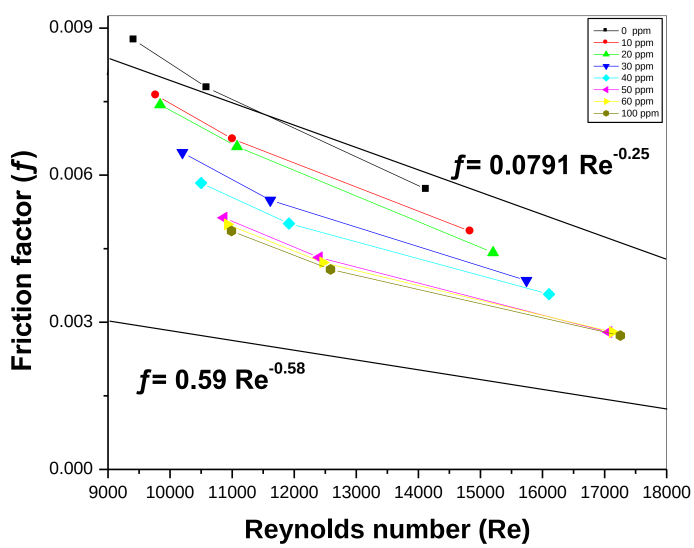

Figure (7): Variation of the friction factor with Reynolds number for Sharara crude oil with PDMS solutions.

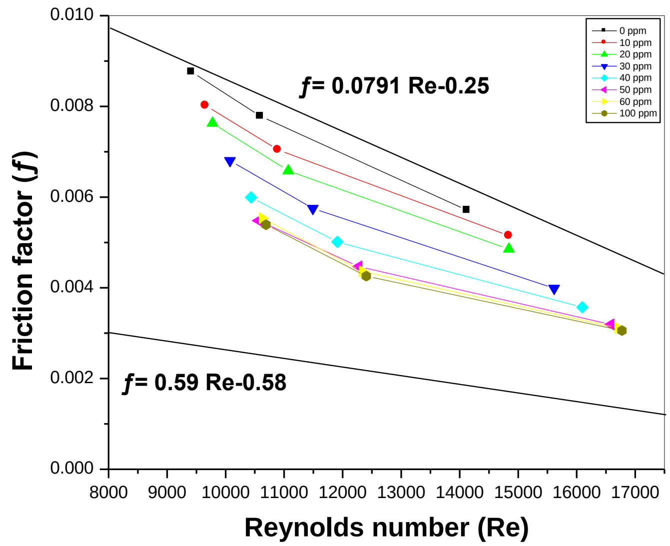

Figure (8): Variation of the friction factor with Reynolds number for Sharara crude oil with PS solutions.

Mathematical Representation of the Results

The results are formulated according to the relation suggested by Abdul Bari et al. (2008).

$$f = k\,Re^{a}\,C^{b} \qquad (8)$$

Where: k, a and b are constants. The data points of all polymers completely fit Equation (8). The constants of this correlation are shown in table (3). However, figures (9) and (10) illustrate the deviation between the observed values of the friction factor and those predicted according to Equation (8) for PDMS and PS solutions for Sharara crude oil respectively.

Table (3): Statistical evaluation of fitting the experimental data to Equation (8).

Sharara crude oil				
		Constants		
Polymers	**Q (l/min)**	**k**	**a**	**b**
PDMS	16	$e^{10.397590}$	-1.644684	-0.072136
	18	$e^{6.854504}$	-1.245958	-0.113823
	24	$e^{15.844843}$	-2.187358	-0.07265
PS	16	$e^{17.677001}$	-2.443940	-0.036561
	18	$e^{13.158926}$	-1.930323	-0.076137
	24	$e^{6.82350}$	-1.225939	-0.147651

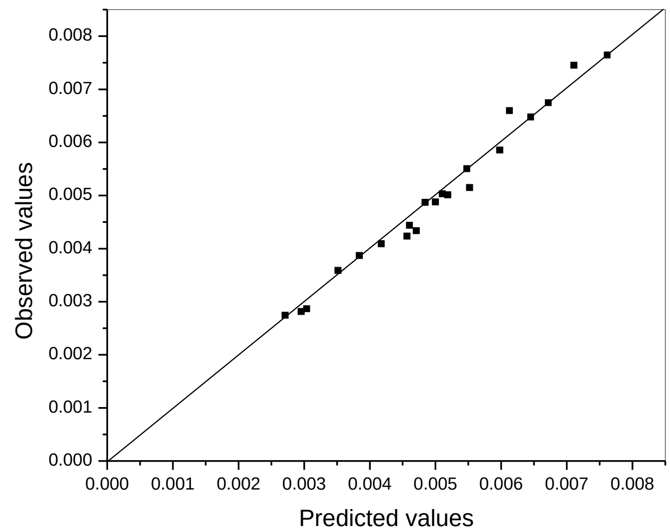

Figure (9): Predicted versus observed values of friction factor for Sharara crude oil with PDMS polymer solution.

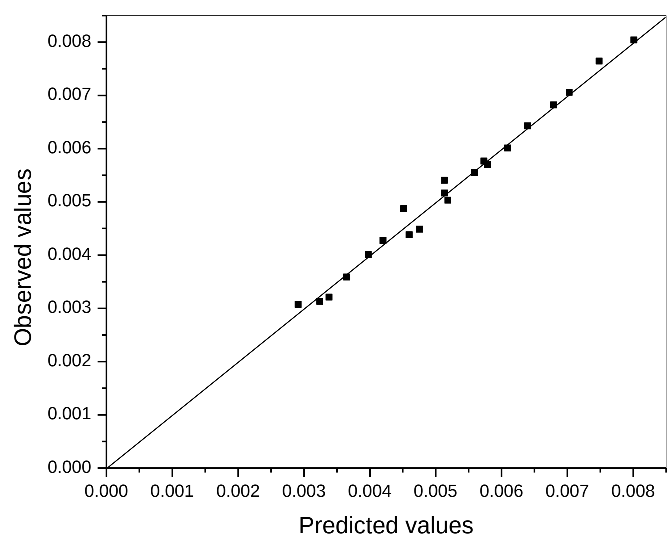

Figure (10): Predicted versus observed values of friction factor for Sharara crude oil with PS polymer solution.

Conclusions

The following conclusions are drawn from the present study:

1. The polymer additives (PS and PDMS) were found to be an effective drag reducing agent (DRA) when used with Sharara crude oil. The addition of these polymers leads to reduce drag force of flowing crude oil and a small amount of dilute polymer solutions required to reach maximum drag reduction. The (%DR) was increased with increasing concentration of polymer additives.

2. The fluid velocity increase with increasing the concentration of polymer and in turn the percentage flow increases (%FI) are increased as the velocity of the solution increased.
3. The best concentration of polymer (PDMS) is 50ppm when added to the Sharara crude oil at velocity of 2.051282 m/sec (24 l/min), which gives the percentage drag reduction (%DR) 29% and percentage flow increase (%FI) 20.7%, while the best concentration of polymer (PS) is 50 ppm for the same flow rate (24 l/min), which gives (%DR) 25% and (%FI) 17.1%. Therefore, drag reduction for PDMS polymer is higher than drag reduction for PS polymer.
4. The friction factor is gradually reduced when the polymer concentration is increased. However, it is noticed that friction factor decreases with increase in Reynolds number for Newtonian fluid flow, however, increase in concentration causes a decrease in friction factor due to slide of layers near the wall on each other.
5. It is noticed that both polymers (PDMS and PS) performance is better in turbulent flow region than laminar flow region, and several experimental data points are located near to Blasius asymptote mainly when the solvent was pure (without polymer), while the data points with polymer solutions are progressively shifted in the direction of Virk asymptote as the polymer concentration increases.
6. The friction factor is accurately correlated with Reynolds number and polymer concentration according to the empirical correlation of the form $f = k\ Re^{a}\ C^{b}$. This correlation showed the friction factor as a function of Reynolds number (Re), and the concentration of additives (C). The results showed good agreement between the observed friction factor values and the predicted ones.

Recommendations

The research topic is very important in oil industry, and for further investigation other variables are advised to be investigated such as oil properties (namely the pour point and flash point); temperature effect on viscosity and API of crude oil; more types of polymers and different mixtures of polymers; and other drag reducing additives such as surfactants, fibers … etc.Furthermore investigation using similar experimental system is recommended to be carried out with different pipe lengths and diameters. Moreover, similar work could also be carried out to study in more detailed the polymer degradation analytically using solvent that could be evaporated at low temperature such as acetone, kerosene, benzene, chloroform … etc.

Acknowledgement

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