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Performance of polyacrylamide as drag reduction polymer of crude petroleum flow

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Abstract The influence of polyacrylamide (PAM) as drag reducing polymer on flow of Iraqi crude oil in pipe lines was investigated in the present work. The effect additive concentration, pipe diameter, solution flow rate and the presence of radius elbows on the percentage of drag reduction (%*Dr*) and the amount of flow increases (%*FI*) were the variables of study. Maximum drag reduction was 40.64% which was obtained with 50 ppm of PAM polymer flowing in straight pipes of 0.0508 m I.D. The dimensional analysis was used for grouping the significant quantities into dimensionless group to reduce the number of variables. The results showed good agreement between the observed drag reduction percent values and the predicted ones with high value of correlation coefficient.

1. Introduction

A spectacular reduction in energy losses in turbulent flows can be achieved by the addition of small amounts of certain polymers. Polymer drag reduction is due to the large elongational viscosity of the polymer solution; this stabilizes the turbulent boundary layer, leading to less turbulent energy generation and hence less dissipation [1]. Drag-reducing polymer solution flows behave like viscoelastic characteristics. The most notable elastic property of the viscoelastic polymer solution is that stress does not immediately become zero when the fluid motion stops, but rather decays with some characteristic time (the relaxation time), which can reach seconds and even minutes. It is generally believed that the frictional drag reduction caused by polymer and surfactant additives in a wall-bounded flow is the consequence of the interaction between viscoelasticity and turbulence in the flow. In a cationic surfactant solution, rod-like micelles can be formed if the surfactant/counterion chemical structures, molar ratios, concentrations, and temperature are under right conditions. This network microstructure imparts viscoelasticity to the solution flow, which was often stated to be responsible for the occurrence of *Dr* [2,3]. Polyacrylamide is a high molecular weight water soluble polymer that used to improve flow. It is used to reduce energy and friction losses and can also be called friction reducers. Water can be injected to simulate oil production. The spontaneous flow of oil and water in crude petroleum production and transportation pipelines is a common occurrence, seen anywhere from the well perforations to the final stages of separation. The goal of the present work was to investigate the validity of the effectiveness of polyacrylamide (PAM) as drag reducing agent with Kirkuk crude oil. Also the effect of additives concentration,

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pipe diameter, solution flow rate and the presence of radius elbows on the percentage of drag reduction (%Dr) and the amount of flow increases (%FI) were the variables of the study.

2. Experimental work

2.1. Liquids

Kirkuk crude oil (Kirkuk governorate – Iraq) was used in the present work (provided from Al-Dura refinery – Iraq). The physical properties of this crude oil were 2.296 viscosity @ 50 °C (c.st), 0.8513 specific gravity, and 35.40 API. The kinematic viscosity of Iraqi crude oil was calculated according to ASTM D-445, while specific gravity was according to ASTM D 1217-81.

2.2. Drag reduction agent

Polyacrylamide (PAM) is a versatile family of synthetic polymers used worldwide and high infinitely soluble in water. It is white dry solid form with molecular weight of 3×10^6. Polyacrylamide was used in concentration of (10, 20, 30, 40 and 50 ppm).

2.3. Description of circulating flow loop system

Fig. 1 represents the schematic diagram of flow system apparatus used in the present work, which consist of reservoir tank of solution ($0.88 \times 0.88 \times 0.88$ m^3 volume), centrifugal pumps (flow rate = 45 m^3/h; power = 25 hp) which used to circulate the solution from the reservoir tank through pipes, while another pump (flow rate = 1 m^3/h; power = 0.5 hp) was connected to the draining exit of the tank., flow meter (12 m^3/h maximum flow rate), valves to control the amount and direction of solution flow rate through the system, pressure gauges, pipes 3 m in length of different inside diameters (0.0508, 0.0254 and 0.0191 m). These pipes are made of commercial carbon steel with relative roughness shown in Table 1.

2.4. Experimental procedure

The preparation of PAM solution by mixing small amount of polymer with a sample of crude oil is the first step in the experimental procedure, then the solution is added into the reservoir tank of crude oil to use in the recirculation closed system. The 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 bypass 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. This procedure was repeated for each pipe diameter and additive concentration.

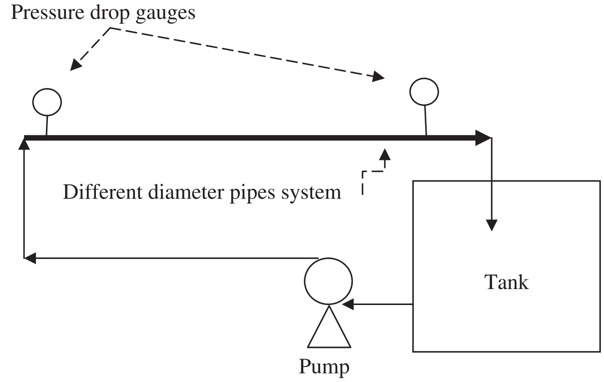

Figure 1 Schematic diagram of flow system.

3. Results and discussion

3.1. Results calculations

Factorial experimental design with 145 runs was used. The following equations were used to calculate Reynolds number (Re), percentage drag reduction (%Dr), percentage flow increase (%FI) [4] and friction factor in terms of fanning friction factor [5] respectively:

$$\mathrm{Re} = \frac{\rho \cdot v \cdot d}{\mu} \quad (1)$$

$$\%Dr = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} \quad (2)$$

$$\%FI = \left(\frac{1}{1 - \left(\frac{\%Dr}{100}\right)^{0.55}} - 1 \right) \times 100 \quad (3)$$

$$f = \frac{\Delta P \cdot d/4L}{\rho \cdot v^2/2} \quad (4)$$

where ρ is density, v liner velocity, d pipe diameter, μ viscosity, ΔP_b ΔP_a pressure drop before and after addition of polymer and L is pipe length. Table 2 shows the percentage of drag reduction, friction factor and percentage flow increase for 50 ppm PAM at different Reynolds numbers. While Table 3 shows the maximum values of %Dr (%Dr_1 in pipe with elbows, %Dr_2 in straight pipe lines) and %FI for PAM polymer reducing agents with Kirkuk crude oil solution, maximum %Dr_2 of 40.64% was obtained using Kirkuk crude oil containing 50 ppm of PAM flowing in straight pipes of 5.08, 2.54 and 1.91 cm I.D. respectively. While the maximum %Dr_1 of 38.46% was obtained in the pipes of different lengths (*i.e.* 1.1 m for 5.08 cm I.D., 0.6 m for 2.54 cm I.D. and 0.35 m for 1.91 cm I.D.) each joined with two elbows of standard radius.

3.2. Effect of polymer concentration

Fig. 2 shows the effect of polymer concentration on drag reduction process. The same figures can be obtained at different conditions. These figures show that the %Dr increases with increasing the additive concentration. The increment in %Dr is ascribed to increases in associated additive molecules in the process of drag reduction. Also, it shows that there is no limited value of concentration after which no further drag reduction occurs within additive concentration 10–50 ppm of polymer. In order to check that the additives 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

Table 1 Relative roughness and length of pipes used.

Pipe inside diameter, m	Relative roughness, ε/d	Length of pipe with elbows, m	Length of straight pipe, m
0.0508	0.000885	4.656	3
0.0254	0.001770	2.378	3
0.0191	0.002362	1.687	3

Table 2 Experimental data for 50 ppm PAM dissolved in the Kirkuk crude oil flowing in 0.0254 m I.D. pipe.

Q (m^3/h)	Re	$\%Dr_1$	f_1	$\%FI_1$
2	6064.69	23.40	0.007651	15.79
3	9097.03	23.81	0.006593	16.13
4	12129.38	24.41	0.006103	16.64
5	15161.72	26.34	0.005809	18.31
6	18194.06	27.56	0.005235	19.40
7	21226.41	28.31	0.004942	20.09
8	24258.75	31.44	0.004621	23.07
9	27291.09	32.50	0.004169	24.13
10	30323.44	34.60	0.003912	26.31
11	33355.78	36.38	0.003662	28.24
12	36388.13	38.46	0.003385	30.61

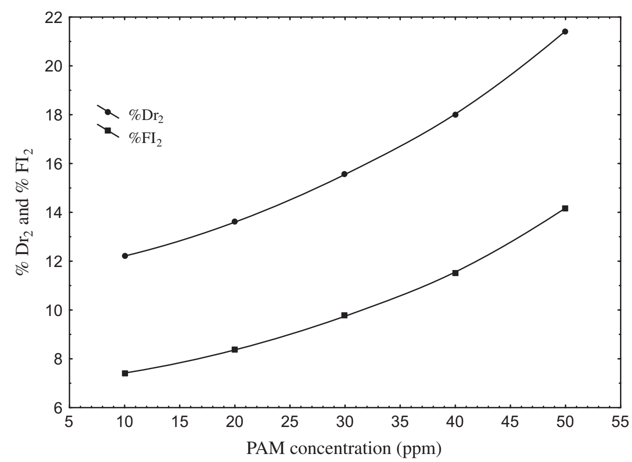

Figure 2 Effect of PAM polymer concentration on drag reduction and flow increase for 0.0508 m pipe diameter and 6 m^3/h flow rate.

physical properties after addition. These results agree with the work of Takashi and Hiromoto [6] and Hayder [7].

3.3. Effect of pipe diameter

Fig. 3 shows the effect of pipe diameter on $\%Dr$. The comparison of $\%Dr$ between the three pipes achieved at constant flow rate through each of them and concentration. The results show that $\%Dr$ increase with pipe diameter increasing within certain additive type and concentration. This increase in $\%Dr$ is attributed to large eddies exist in the pipe of large diameter, which absorb large amount of energy from the main flow. While in the small pipes, the number of formed small eddies were larger than large eddies formed in the large pipes, this small eddies needed a large amount of energy absorbed from main flow to overcome the resistance of viscosity and then complete its shape. Not all small eddies absorb equal amount of energy, some of them absorb amount of energy not be able to overcome viscous resistance, and then eventually disappear causes loss in the energy of main flow. While the other eddies absorb enough energy and enable to overcome viscosity resistance, the $\%Dr$ in small pipes is lower than in large pipes due to small eddies which absorb small amount of energy not enable it to overcome viscosity resistance. The same conclusion was obtained by Abdul-Hakeem [8].

3.4. Effect of flow rate

Fig. 4 shows the effect of solution velocity (v) on the percentage drag reduction ($\%Dr$) in terms of volumetric flow rate. The results show that, the drag reduction percentage increases with increasing fluid velocity. Increasing the fluid velocity means increasing the degree of turbulence inside the pipe, this will provide a better media to the drag reducer to be more effective. The behavior of increasing $\%Dr$ with velocity of fluid may be explained due to relation between degree of turbulence controlled by the solution velocity and the additive effectiveness. The same results obtained by Nam-Jin Kim et al. [9], the drag reduction were larger at high Reynolds number.

3.5. Effect of friction

Fig. 5 shows the friction factor for various Re, pipe diameter, additives type and additive concentrations. These figures are divided into four regions. These regions are [10]:

Table 3 Maximum values of $\%Dr$ and $\%FI$ at 50 ppm PAM concentration.

Pipe diameter (m)	Flow rate (m^3/h)	Max. $\%Dr_1$	Max. $\%Dr_2$	Max. $\%FI_1$	Max. $\%FI_2$
0.0508	12.00	38.46	40.64	30.61	33.22
0.0254	12.00	37.31	35.28	29.28	27.04
0.0191	6.00	24.46	23.51	16.68	15.88

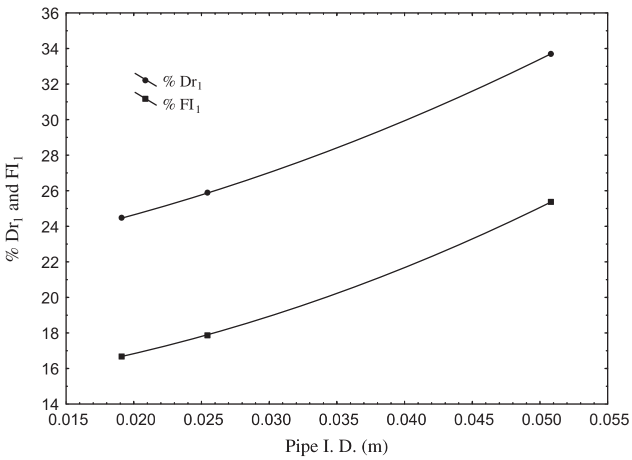

Figure 3 Effect of pipe diameter on drag reduction for 50 ppm PAM concentration and 6 m^3/h flow rate.

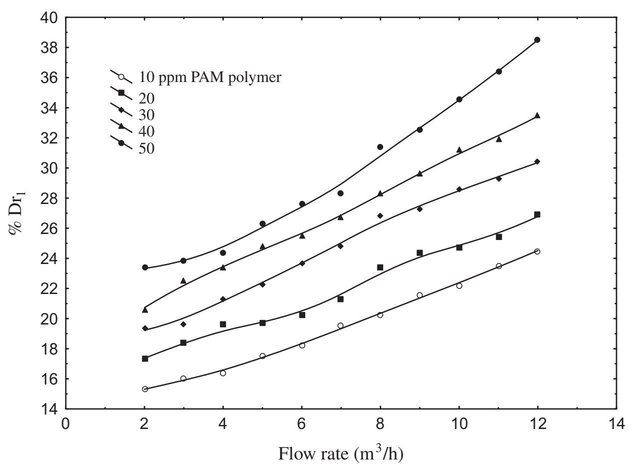

Figure 4 Effect of flow rate on drag reduction for different PAM concentration flowing in 0.0254 m I.D. pipe.

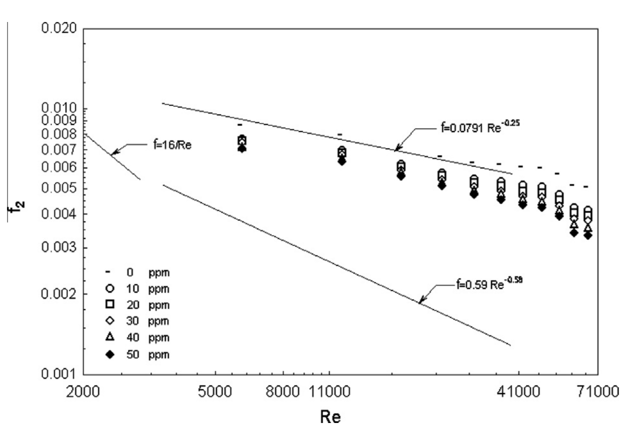

Figure 5 Friction factor versus Reynolds number at different concentration of PAM polymer dissolved in Kirkuk crude oil flowing through 0.0254 m I.D. pipe.

1. Laminar flow region (Re < 2300), where the friction factor follows Poisuell's law as follows:

$$f = 16\mathrm{Re}^{-1} \tag{5}$$

2. Transition region (Re = 2300–3000), where the flow change from laminar to turbulent flow. Friction coefficient rises rapidly.
3. Turbulent region (Re > 3000), where the friction factor follow Blasius law:

$$f = 0.0791\mathrm{Re}^{-0.25} \tag{6}$$

4. Virk asymptote region, which is suggested by Virk to represent the greatest possible fall in resistance in which the relation between friction factor (f) and Re does not depend on the nature of the additives or pipe diameter. The formula for Virk is:

$$f = 0.59\mathrm{Re}^{-0.58} \tag{7}$$

This figure showed that the friction factor decreased with decreasing the pipe diameter, with increasing concentration of additive and with increasing fluid velocity. From this figure, it can be noticed that the most of experimental data points are located at or close to Blasius asymptote when the solvent was pure. After the addition of additive, the data points positioned toward Virk asymptote which represent the maximum limits of drag reduction. It was difficult to reach these limits of lowering resistance because of the higher concentration of additives is required to achieve this condition. But it must be taken into account that higher concentration should not affect solvent properties.

4. Conclusion

The PAM polymer was found to be effective drag reducing agent when used with Kirkuk crude oil. Drag reduction percent or flow increase percent is increased as velocity of solution increased. Drag reduction percent is increased with increasing concentration of additive. It is observed that the additive does not affect the physical properties of used crude oils.

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