Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

Experimental Investigation of Drag Reduction by a Polymeric Additive in Crude Oil Flow in Horizontal Pipe

Open Access

Farhan Lafta Rashid[1,*], Haider Nadhom Azziz[1], Shaheed Mahdi Talib[2]

[1] Department of Petroleum Engineering, University of Kerbala, Iraq
[2] General Directorate of Education in Kerbala, Iraq

ARTICLE INFO

Article history:
Received 5 April 2019
Received in revised form 1 May 2019
Accepted 22 June 2019
Available online 15 August 2019

ABSTRACT

Companies of oil transportation are undergoing a need to rise their efficiencies and capabilities of transport. The frictional pressure drags or drops, taking charge of energy losses in oil pipelines, may be reduced by adding long-chain polymers of drag reduction agent (flow improvers). In this work, a Drag Reducing Agent (DRA) has been employed to reduce the drag of Iraqi crude oil using Poly Acrylic Acid (PAA) at different concentrations (0, 50, 100, 150, 200 and 250 ppm). The test rig used in present work consists of a crude oil reservoir of dimensions (0.75 x 0.75 x 0.75 m) and a pump (flow rate =30 L/min., maximum head=30 m, maximum power =0.74 hp). This pump is used to circulate the treated crude oil from the reservoir through the pipe. Results show that using DRA reduces the crude oil viscosity, using a DRA concentration of 250 ppm decreases the pressure drop by 28.8 % for pipeline capacity, pipe diameter and length of 0.0081 m^3/s, 0.0508 m and 5 m, respectively. In addition, a maximum drag reduction of 16 % has been achieved at the highest concentration (250 ppm). Therefore, the DRA addition saves the pumping power and increases the produced flow by 28.48 % and 4.05 %, respectively.

Keywords:
Drag reduction; polymeric additive; rheological characterization; pumping power

1. Introduction

Adding certain polymers or surfactant with small amounts can reduce turbulent friction of fluids [1–3], the first trial was adopted by Forrest and Grierson [4], they found a reduction in turbulent pipe energy loss of flow for suspensions of wood pulp fiber in water. Mysels [5] discovered that the gasoline skin friction in pipe flow was reduced by adding aluminum disoap. Toms [6] noticed the phenomenon of drag reduction, while doing research of polymer degradation, Toms also discovered that using polymethyl methacrylate in monochlorobenzene reduces the drag of turbulent skin friction by up to 80% [7-9].

Drag reduction agents are described as a thick, viscous liquid with the appearance of old honey and highly viscoelastic. DRAs used in products pipelines and oil are chains of hydrocarbons and thus

[*] *Corresponding author.*
E-mail address: engfarhan71@gmail.com (Farhan Lafta Rashid)

should have no effect on physical properties of refining processes or products. Solutions of DRA-solvent are shear degradable, viscoelastic, time-independent, and non-Newtonian fluids [10, 11]. Bayode *et al.,* studied the drag reduction of turbulent flow using polyacrylamide in different pipe section (cylindrical, rectangular, and square). Various levels of degradation were applied on the polymer solutions by recirculating in the experimental rigs. Relaxation times of polymer were monitored to scale approximately as $t^{-0.5}$. Stream wise velocity (U^+) profiles at different levels of drag reduction showed a thickening of the buffer layer [12]. Zainab discovered a new additives complex for the use as drag reduction. It was observed that these additives can reduces the drag more than the individual case. concentration is the more variable which played a big role in their performance [13]. Farhan *et al.,* studied the effect of using Poly Vinyl Pyridine (PVP) as drag reduction agent to minimize the drag of a crude oil by different concentrations (0, 500, 750, 1000, 1250 and 1500 ppm). The flow index values have a significant decrease at a concentration range of (750-1500 ppm), and the lowest flow index value is reached at a PVP concentration of (1000 ppm) [14]. Sealtial and Yanuar [15] used calcium carbonate as environmentally friendly substance to initiate drag reduction in a pentagon spiral pipe. The pure water-ethylene glycol mixed with ratio 60:40 and used as the liquid and calcium carbonate 80-100 nm in size as the powder. Concentrations of calcium carbonate were 100, 300, and 500 ppm. At the Reynolds number $4x10^4$, the maximum drag reduction rate was 21.77% for the circular pipe and 30.89% by the pentagon spiral pipe. Many researchers studied the effect of adding nanomaterials on fluid flow and heat transfer [16-19].

The objective of the present work is to investigate the effectiveness (%DR) of drag reducing agent (PAA) on drag reduction of Iraqi crude oil. This can be accomplished by studying the effect of different additive concentrations on Rheological characterization, pressure drop (or head loss), pumping power saving and flow increase.

2. Experimental Part

2.1 Liquid

Iraqi crude oil was used in this test as a flowing liquid which is supplied from Al-Najaf refinery–Iraq. The crude oil physical properties at 25 ^{o}C are: viscosity =27.55 cP, specific gravity =0.89.

2.2 Drag Reducing Agent

Poly acrylic acid is soluble in polar solvents such as water. It is also soluble in many alcohols, such as ethanol and methanol as well as in more exotic solvents such as the heavy eutectic solvent created by choline chloride and urea. So, it has prime wetting properties and can form films [20, 21]. In the present work, poly acrylic acid is used at different concentrations 50, 100, 150, 200 and 250 ppm.

2.3 Description of Circulating Flow Loop System

The test rig used in present work consists of a crude oil reservoir of dimensions (0.75 x 0.75 x 0.75 m) and a pump (flow rate =30 L/min., maximum head=30 m, maximum power =0.74 hp). This pump is used to circulate the treated crude oil from the reservoir through the pipe. A flow meter is also used to measure the flow rate (flow rate=0.0081 m^3/s, accuracy of ± 0.004%) of the treated crude oil through the system. Two pressure gauges (accuracy of ±0.1%) are fixed at two different point on the pipe to measure the pressure drop. A stainless-steel pipe of 5 m in length and inside diameter of 0.0508 m is used. A schematic diagram of the test rig is shown in Figure 1. In addition, a viscometer (accuracy of ±0.2%) and density tester (accuracy of ±0.1%) are used to measure the viscosity and density of the crude oil as shown in Figure 2 and Figure 3, respectively. After the experimental apparatus is built, the crude oil treated with different PAA concentrations is circulated through the flow loop system to measure different affecting parameters.

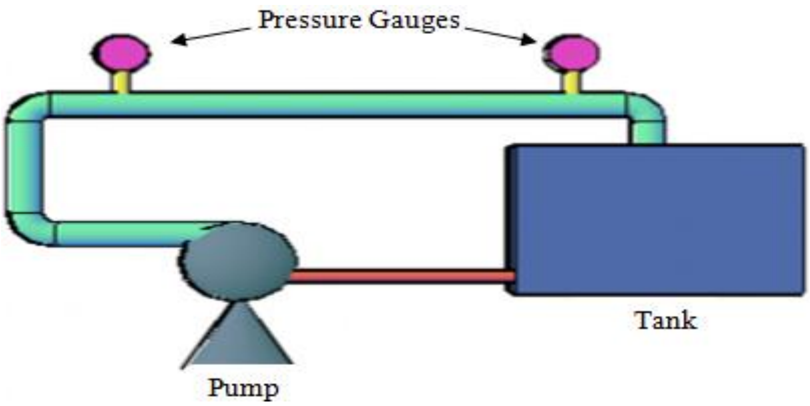

Fig. 1. Circulating flow loop system

Fig. 2. Viscometer cone-plate


Fig. 3. Density tester

3. Results and Discussion

In this work, Eq. (1)-(4) are used to predict the flow Reynolds number (Re), percentage of the flow increase (%FI), percentage of the drag reduction (%DR), and Darcy friction factor, respectively [22, 23]

$$Re = \frac{\rho v d}{\mu} \tag{1}$$

$$\%FI = \left(\frac{1}{1-\left(\frac{DR\%}{100}\right)^{0.55}} - 1\right) x100 \tag{2}$$

$$\%DR = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} \tag{3}$$

$$f = \frac{2 d \Delta P}{L \rho v^2} \tag{4}$$

where v is the linear velocity, ρ is fluid density, μ is dynamic viscosity, d is pipe diameter, ΔP_b and ΔP_a are the pressure drop before and after the DRA is added, respectively and L is the pipe length.

3.1 Rheological Characterization

PAA polymer is added to the crude oil as a drag reducer at different concentration (0, 50, 100, 150, 200 and 250 ppm) to investigate their effect on the flow characteristics of the Iraqi crude oil. Figure 4 shows that the density of the crude oil increases as the concentration of the PAA increases. On the other hand, the viscosity of the crude oil will be reduced as shown in Figure 5.

Figure 6 illustrates the variation of shear stress with shear rate of the crude oil treated with different concentrations of DRA (0, 50, 100, 150, 200 and 250 ppm). It is observed that at concentration of 0 ppm (pure crude oil), almost a linear increase in the shear stress is shown with the shear rate. This concentration exhibits the highest values of the shear stress at all values of the shear rate compared with other concentrations. In addition, a considerable decrease in the shear stress is obtain by adding the DRA to the crude oil. This reduction varies as the concentration of the DRA varies and the highest decrease (lowest shear stress) is observed at a concentration of 250 ppm. It is also observed that the shear stress is decreased as the PAA concentration is increased.

Figure 7 shows relationship between viscosity and shear rate for the crude oil treated with different concentrations of DRA (0, 50, 100, 150, 200 and 250 ppm) at a constant temperature of 25^{o}C. From this figure, it is shown that adding the DRA reduces significantly the viscosity of the crude oil and the reduction depends on the DRA concentration in the crude oil. Consequently, the lowest and highest reduction is obtained at 50 and 250 ppm, respectively. Effect of the added DRA in reduction the pipeline pressure drop is not concerned to its effect on viscosity but it is attributed to its effect of reduction the turbulence energy degree through the pipeline, thereby reducing gradually the shear stress which is clearly presented in Figure 8.

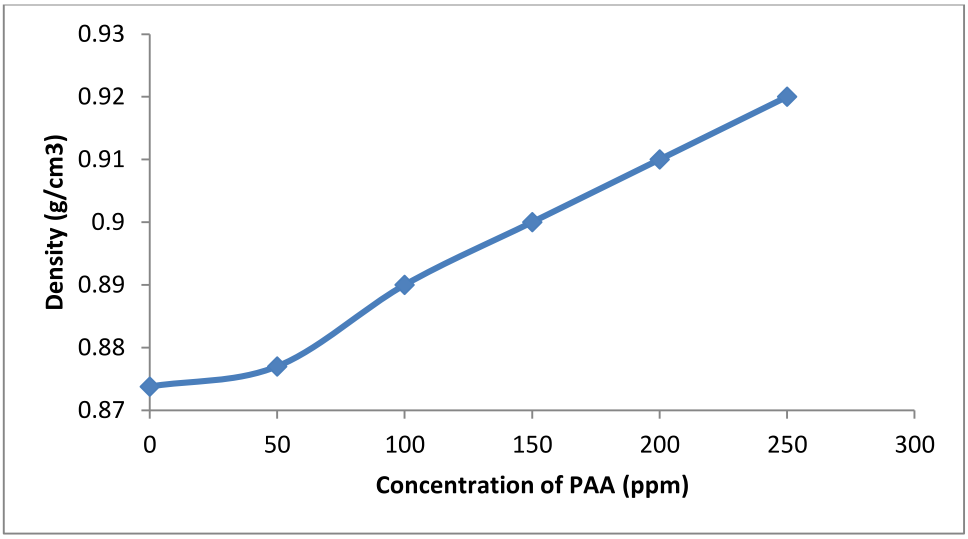

Fig. 4. Crude oil density as a function of PAA concentration

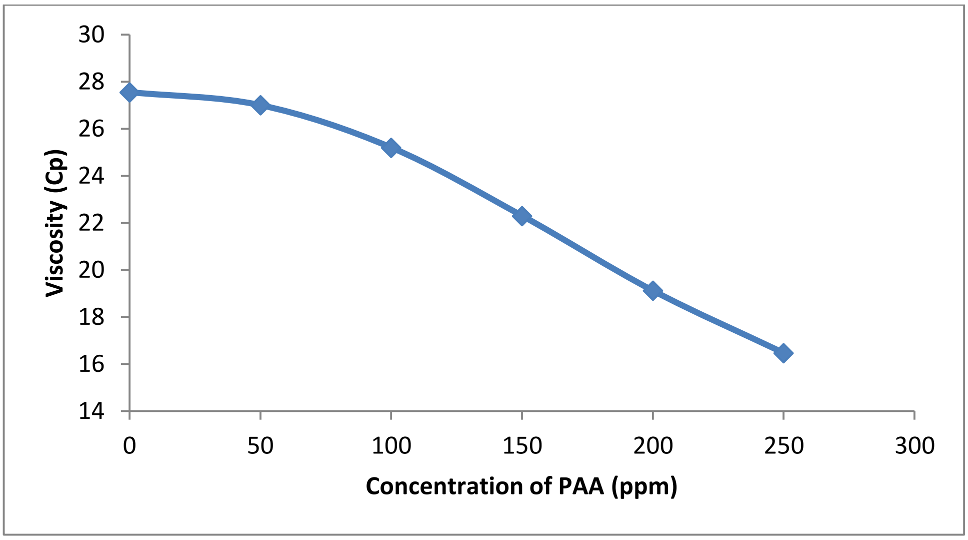

Fig. 5. Crude oil viscosity as a function of PAA concentration

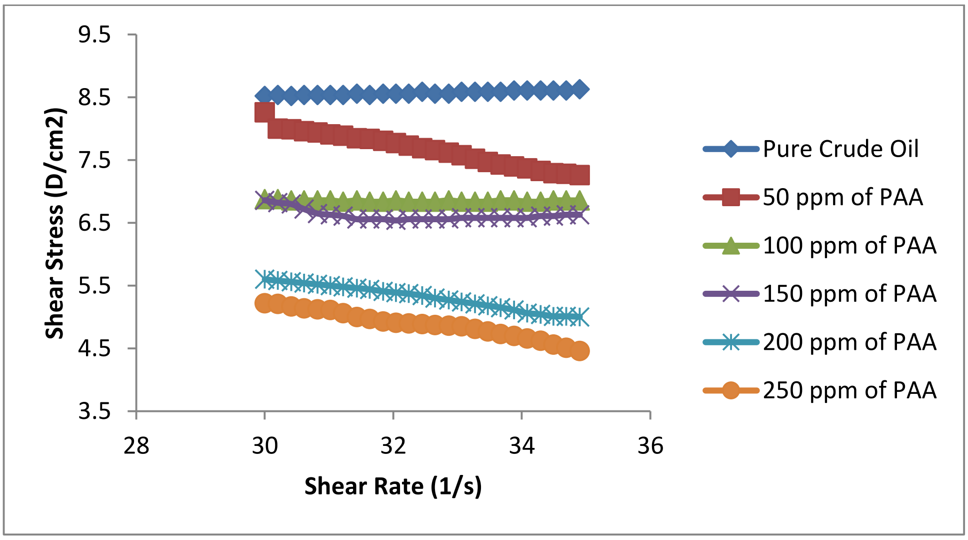

Fig. 6. Crude oil shear stress as a function of shear rate

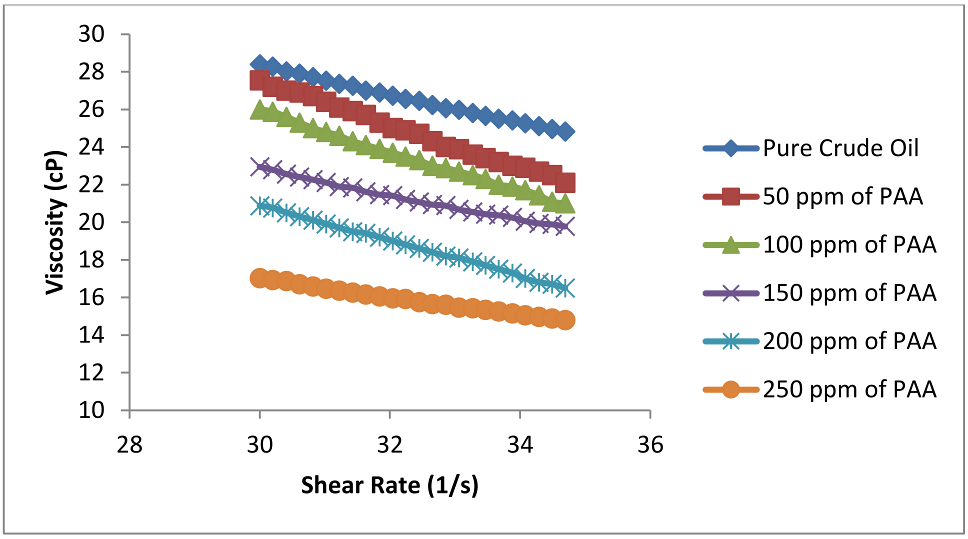

Fig. 7. Crude oil viscosity as a function of shear rate

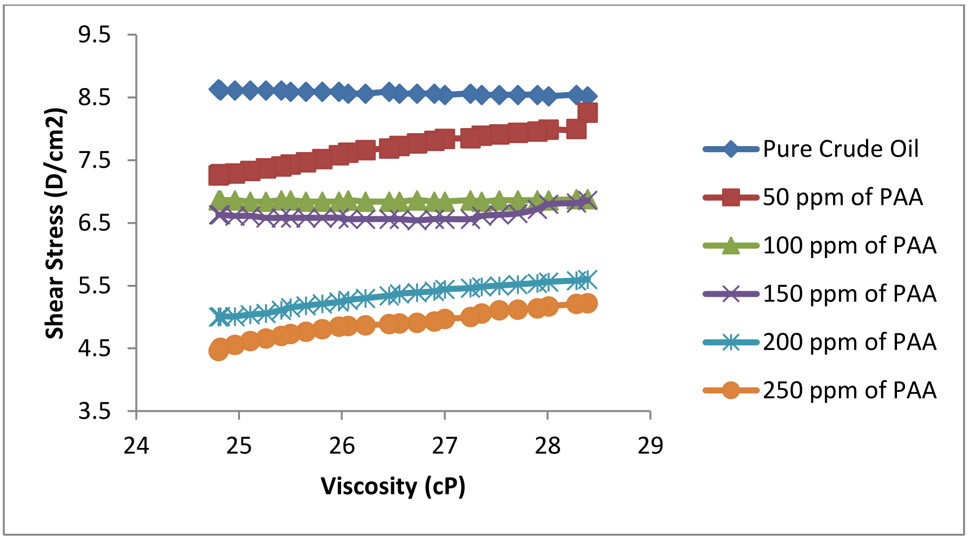

Fig. 8. Crude shear stress as a function of viscosity

3.2 Crude Oil Flow Characteristics

Figure 9 shows variation of pressure drop with different concentrations of the PAA. It is shown that the pressure drop decreases with increasing the PAA concentration. This is because that the addition of DRA (PAA) reduces the viscosity and therefore the Reynolds number will increase which leads to decrease the friction factor, thereby the pressure drop decreases.

Figure 10 manifests the PAA concentration effect on the process of drag reduction. This figure shows the increase in the %DR with increasing the concentration of PAA. The increment in %DR is regarded to the increase in the associated additive molecules in the drag reduction process. A maximum drag reduction of 16 % is achieved at the largest concentration (250 ppm). Therefore, the DRA addition increases the saving in pumping power as shown in Figure 11.

Another benefit of the DRA addition is increasing the flow as shown in Figure 12. The maximum flow increase is found to be 4.1 % which is obtained at PAA concentration of (250 ppm).

So the addition of drag reducing agent reduces the friction factor ratio as a result of decreasing the crude oil viscosity, this can be shown in Figure 13.

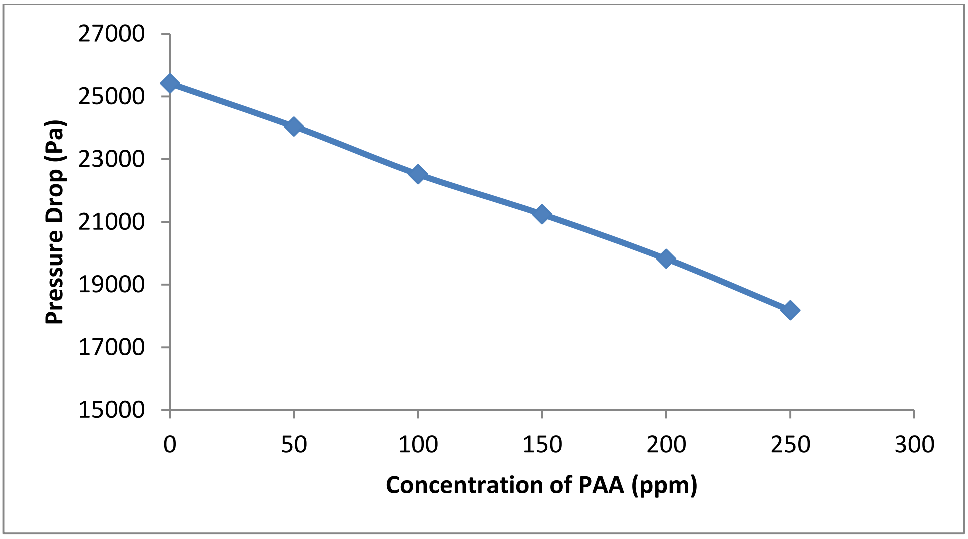

Fig. 9. Pressure drop as a function of PAA concentration

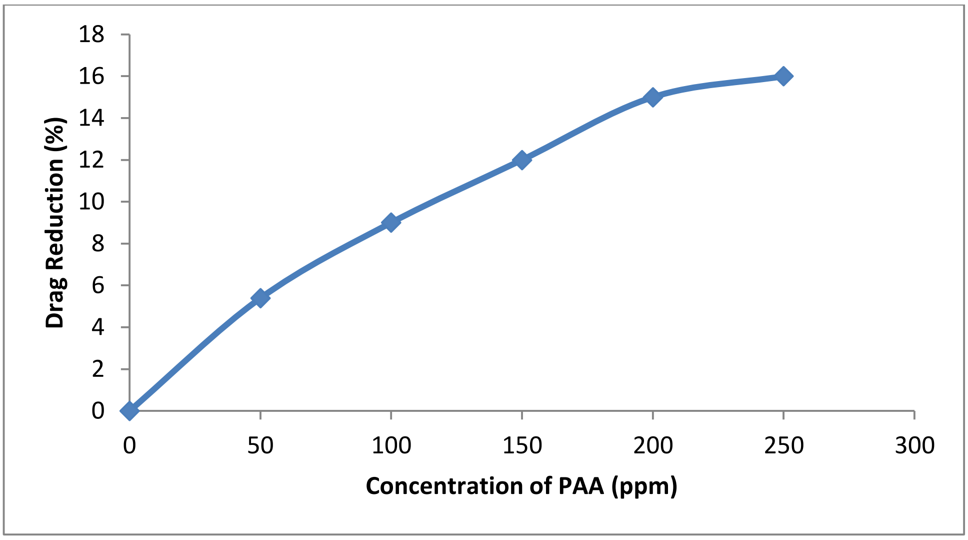

Fig. 10. Drag reduction as a function of PAA concentration

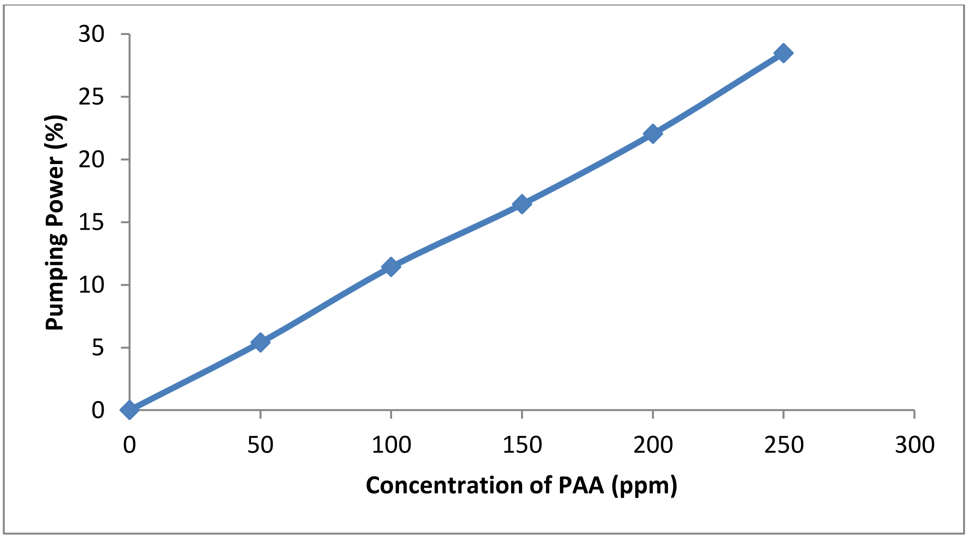

Fig. 11. Pumping power as a function of PAA concentration

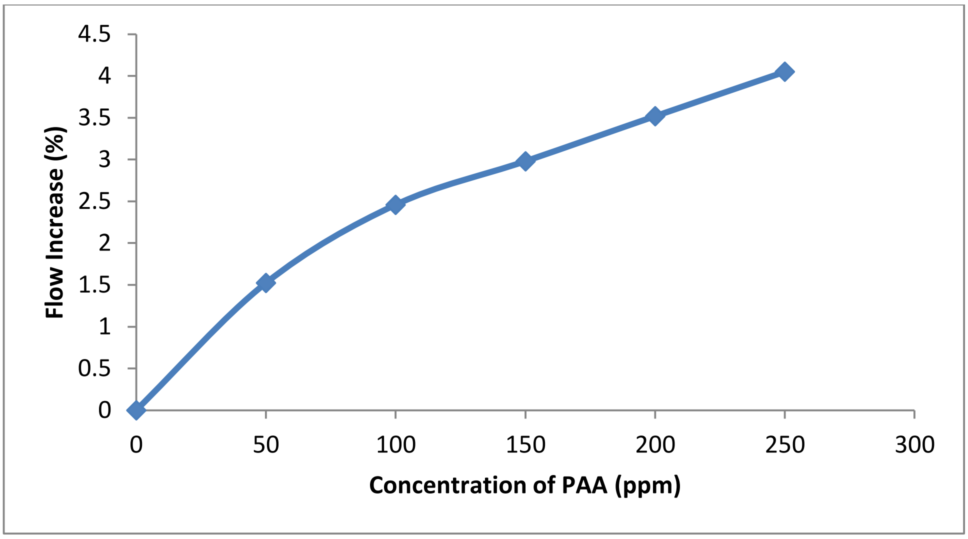

Fig. 12. Flow increase as a function of PAA concentration

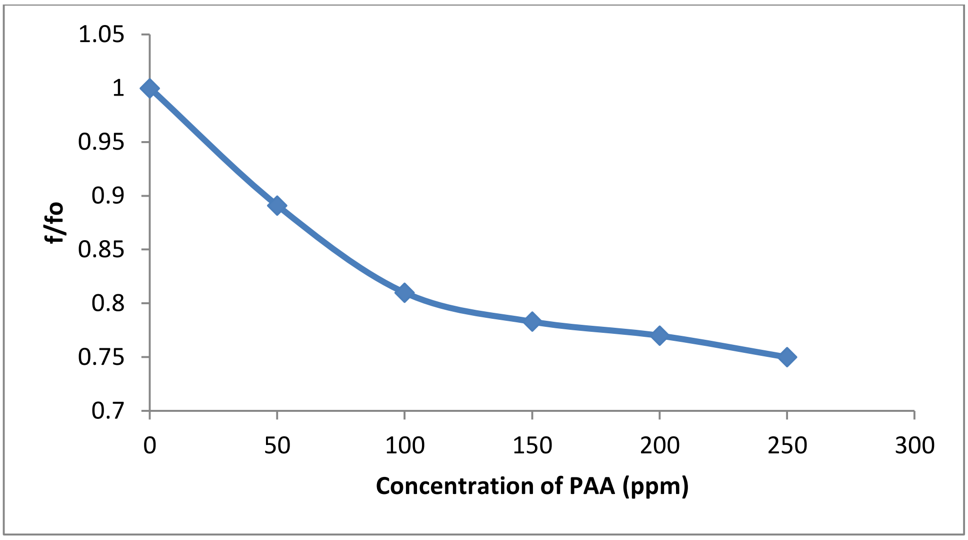

Fig. 13. Friction factor ratio as a function of PAA concentration

3. Conclusions

The drag reduction effect is very important in many applications such as petroleum flow in pipeline systems. The drag reduction behavior of PAA has been studied. It is concluded that adding a small amount of PAA concentration can provide a significant impact on the characteristics of the fluid flow in the turbulent flow. So, it is proven that the PAA is an effective drag reducing agent in the fluid turbulent flow, especially, at relatively high concentration of the PAA. The percentage of the drag reduction also increases due to the reduction of the crude oil viscosity. Besides that, pressure drop (or head loss) also decreases as the PAA concentration increases. Accordingly, the pumping power and the flow can be optimized. Thus, the PAA additive is found to be an efficient drag reducing agent for the Iraqi crude oil.

References

[1] Hadri, Ferhat, and Sylvain Guillou. "Drag reduction by surfactant in closed turbulent flow." *Int. J. Eng. Sci. Technol.* 2, no. 12 (2010): 6876–6879.

[2] Wang, Yi, Bo Yu, Jacques L. Zakin, and Haifeng Shi. "Review on drag reduction and its heat transfer by additives." *Advances in Mechanical Engineering* 3 (2011): 478749.

[3] Hiroshi Suzuki, Yuta Higughi, Hirofumi Watanabe, Yoshiyuki Komoda, Shogo Ozatna, Takuya Nishimara and Nobuyuki Takenaka. "Relaxation behavior of a drag-reducing cationic surfactant solution." *Nihon Reoroji Gakkaishi* 40 (2012): 85–90.

[4] Forrest, Frank, and G. A. Grierson. "Friction losses in cast iron pipe carrying paper stock." *Paper Trade Journal* 92, no. 22 (1931): 39-41.

[5] Mysels, K. J. "Early experiences with viscous drag reduction." In *AIChE Chemical Engineering Progress Symposium Series III*, vol. 67, pp. 45-49. 1971.

[6] Toms, Be A. "Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers." *Proc. of In. Cong. On Rheology, 1948* 135 (1948).

[7] Drappier, J., T. Divoux, Y. Amarouchene, F. Bertrand, S. Rodts, O. Cadot, J. Meunier, and Daniel Bonn. "Turbulent drag reduction by surfactants." *EPL (Europhysics Letters)* 74, no. 2 (2006): 362-368.

[8] Prajapati, Ketan. "Interactions between drag reducing polymers and surfactants." Master's thesis, University of Waterloo, 2009.

[9] Li, Feng-Chen, Yasuo Kawaguchi, Bo Yu, Jin-Jia Wei, and Koichi Hishida. "Experimental study of drag-reduction mechanism for a dilute surfactant solution flow." *International Journal of Heat and Mass Transfer* 51, no. 3-4 (2008): 835-843.

[10] Lester, C. B. "Drag reduction agents." *Oil and Gas Journal* 4 (1985): 51-56.

[11] Martínez-Palou, Rafael, María de Lourdes Mosqueira, Beatriz Zapata-Rendón, Elizabeth Mar-Juárez, César Bernal-Huicochea, Juan de la Cruz Clavel-López, and Jorge Aburto. "Transportation of heavy and extra-heavy crude oil by pipeline: A review." *Journal of petroleum science and engineering* 75, no. 3-4 (2011): 274-282.

[12] Owolabi, Bayode E., David JC Dennis, and Robert J. Poole. "Turbulent drag reduction by polymer additives in parallel-shear flows." *Journal of Fluid Mechanics* 827 (2017).

[13] Yousif Zainab. "Drag Reduction Study of Xathan Gum with Polydiallyldimethylammonium Chloride (PDDAC) Solutions in Turbulent Flow." *Engineering and Technology Journal* 36, no. 8 (2018): 891-899.

[14] Farhan Lafta Rashid, Auda J.Braihi, Ahmed Hashim, Akram Jassim Jawad. "Drag Reduction of Iraqi Crude Oil Flow in Pipelines by Polymeric Additives." *International Journal of Mechanical Engineering and Technology* 9, no. 13 (2018): 1049–1060.

[15] Sealtial Mau and Yanuar. "Effect of Calcium Carbonate Solution on Drag Reduction in a Pentagon Spiral Pipe." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 46, no. 1 (2018): 41-48.

[16] Nura Mu'az Muhammad, Nor Azwadi Che Sidik. " Utilization of Nanofluids in Minichannel for Heat Transfer and Fluid Flow Augmentation: A Concise Research Design". *Journal of Advanced Research Design* 50, no. 1 (2018): 18-29.

[17] S. B. Abubakar, and N. A. Che Sidik. "Numerical Prediction of Laminar Nanofluid Flow in Rectangular Microchannel Heat Sink". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 7, no.1 (2015): 29-38.

[18] N. Mat Isa, A. F. Ab Rahman and A. Sadikin." Numerical Simulation of Splitting Devices in Horizontal Pipeline". *Journal of Advanced Research in Applied Mechanics* 5, no.1 (2015): 8-14.

[19] S. Zainal, C. Tan , C. J. Sian and T. J. Siang. " ANSYS simulation for Ag/HEG Hybrid Nanofluid in Turbulent Circular Pipe". *Journal of Advanced Research in Applied Mechanics* 23, no. 1 (2016): 20-35.

[20] Wohlfarth, C. "Thermodynamic Properties of Polymer Solutions." *Landolt-Bornstein, New Series, Group VIII* 6 (2010).

[21] Sapir, Liel, Christopher B. Stanley, and Daniel Harries. "Properties of polyvinylpyrrolidone in a deep eutectic solvent." *The Journal of Physical Chemistry A* 120, no. 19 (2016): 3253-3259.

[22] Darby, Ronald, Ron Darby, and Raj P. Chhabra. *Chemical engineering fluid mechanics, revised and expanded*. CRC Press, 2001.

[23] Holland, F., and R. Bragg. *Fluid flow for chemical and process engineers*. Elsevier, 1995.