The 1st Regional Conference of Eng. Sci. NUCEJ Spatial ISSUE vol.11,No.1, 2008 pp 52-59

Effect of Molecular Weight on Turbulent Drag Reduction with Polyisobutylene

Dr. Jabir Shanshool
Chemical Engineering Department, Collage of Engineering, Nahrain University

Haider M. T. Al-Qamaje
Chemical Engineering Department, Collage of Engineering, Nahrain University

Abstract

Turbulent drag-reduction efficiency of polyisobutylene with three different, very high molecular weights was studied in a build-up closed loop gas oil circulation system. The turbulent mode was produced via a positive displacement gear pump to avoid mechanical degradation of polymer chains during the experimental period. Three molecular weights $2.9*10^6$, $4.1*10^6$ and $5.9*10^6$ g/mol dissolved in reformate were used as additives in order to investigate the effect of molecular weight on drag-reduction rate. The effect of polymer concentration was investigated over a range up to 70 wppm in gas oil flow Reynolds number 8341 to 35747 as well as in 1.25 inch inside pipe diameter. A gradual increase of drag reduction and throughput was achieved by increasing the polymer concentration and gas oil flow rate. Friction factor was calculated from the experimental data. For untreated gas oil pipelining, friction factor values lies near Blasuis asymptotes. While by addition of polymer drag reducer into the flow, the friction factor values were positioned towards Virk maximum drag-reduction asymptotes, noticeably for the highest molecular weight type. Furthermore the investigation showed that the degree of molecular weight is significantly in drag reduction performance. Correlation equations were suggested to predict the effect of flow parameters, concentration, flow rate and finally polymer molecular weight on pressure drop reduction. The results of the correlations showed good agreement between the observed and predicted pressure drop reduction values, with a higher than 97% correlation coefficient.

Keywords: Drag reduction, High molecular weight polymers, Turbulent flow.

Introduction

Generally large amount of energy loss due to friction occurs in many cases of turbulent flow. However, it is well known that turbulent drag reduction which is drastic reduction of frictional resistance can be easily observed by injection a minute amount of polymeric additives in turbulent flow (1). Treated solvents undergoing a turbulent flow in a pipe thereby require a low pressure drop to maintain the same volumetric flow rate.

The industrial application of drag reduc-tion can be found in many areas such as pipelining of crude oil and its fractions (3), fire-fighting (4) and closed-circuit pumping installations, such as cent-ral heating system (5). The first major application Trans-Alaska oil pipeline system (2). These applications showed the high ability of polymers in reducing drag and increasing oil flow rate without the need for any additional pumping power or new pipelines.

Various drag-reducing additives are available, such as flexible long- chain macromolecules, colloidal surfactants and suspension of fine, insoluble particles (8). Effective polymeric Drag- reducing additives are considered to be flexible, linear with high molecular weight, such as polyethylene oxide, polyacrylamide and polyisobutylene (9).

Polyisobutylenes are highly olefine hydrocarbon polymers, composed of long, straight chain macromolecules containing only chain- end olefin bonds. This molecular structure leads to chemical inertness and resistance to chemical or oxidative attack, and solubility in hydrocarbon solvents (7).

The dependence of drag reduction efficiency is known to be a function of polymer molecular weight, polymer concentration, and the degree of turbulence. However, the usage of these polymers is limited because of their susceptibility to flow induced mechanical and/or chemical degradation of the polymer molecules and marginal economic incentive, have slowed its exploitation (10).

Experiments show that the higher of molecular weight, the more effective a given polymer as a drag reducer (11). Polymers with a molecular weight below one million seem to be ineffective. The longer polymer chain provides more chance for entanglement and interaction with the flow. It has been confirmed that the extension of the polymer chain is critical for drag reduction. The most effective drag reducing polymers are essentially in linear structure, with maximum extensivity for a given molecular weight. Poly (ethylene oxide), polyisobutylene and polyacrylamide are typical examples of linear polymers [11].

The major objective of the present work is concerned with the studying the effect of molecular weight of polymeric additives on effectiveness of drag reduction on gas oil turbulent flow. Three potentially economically available polyisobutylene polymers (Oppanol types) with different molecular weights ranging between 2.5 to about six million have been studied in a laboratory scale turbulent pipe flow loop.

Experimental work

The drag-reducing polymers were polyi-sobutylene types Oppanol B 150, 200, and 250 of molecular weight 2.6, 4.1 and 5.9 million respectively which purchased from BASF Company, Germany. Light gas oil supplied from Al-Durra refinery, was used as pipelining liquid, reformate of 58 API gravity, supplied from Al- Durra refinery was used to dissolve the three Oppanol B polymers.

The method of solution preparation adapted here was to make 2 % by weight concentration using an electrical shaker, type Kottermann 4010, Germany, to avoid polymer degradation. Homogenous solutions were obtained, after 2, 3 and 5 days shaking at room temperature for Oppanols B 150, B200 and B 250 respectively.

The drag reduction experiments were carried out in an available laboratory circulation loop [12], as shown in figure (1). The 0.49 m^3 reservoir tank was supported with seamless carbon steel pipes of 1.25 inch inside diameter in addition to 2 inch by pass to control the flow. The test sections of 3 m long were placed away from the entrance length required. A gear pump of 1440 rpm was used to deliver the fluid at high turbulence.

Percentage drag-reduction (%DR) was calculated based on pressure drop data through the test section, as follows [6]

$$\%DR. = \frac{\Delta P_{untreated} - \Delta P_{treated}}{\Delta P_{untreated}} * 100 \quad (1)$$

Where:

$\Delta P_{untreated}$ is the friction pressure drop for untreated gas oil

$\Delta P_{treated}$ for treated gas oil, both measured at the same volumetric flow rate.

Results and Discussion

Pressure drop of flowing treated gas oil was measured at the two points of the test section. The values of pressure drop saving are calculated between measured pressure drop in the test section for untreated gas oil and those for gas oil at a given flow rate and pipe diameter, as follows

$$\Delta P_{decrease} = \Delta P_{untreated} - \Delta P_{treated} \quad (2)$$

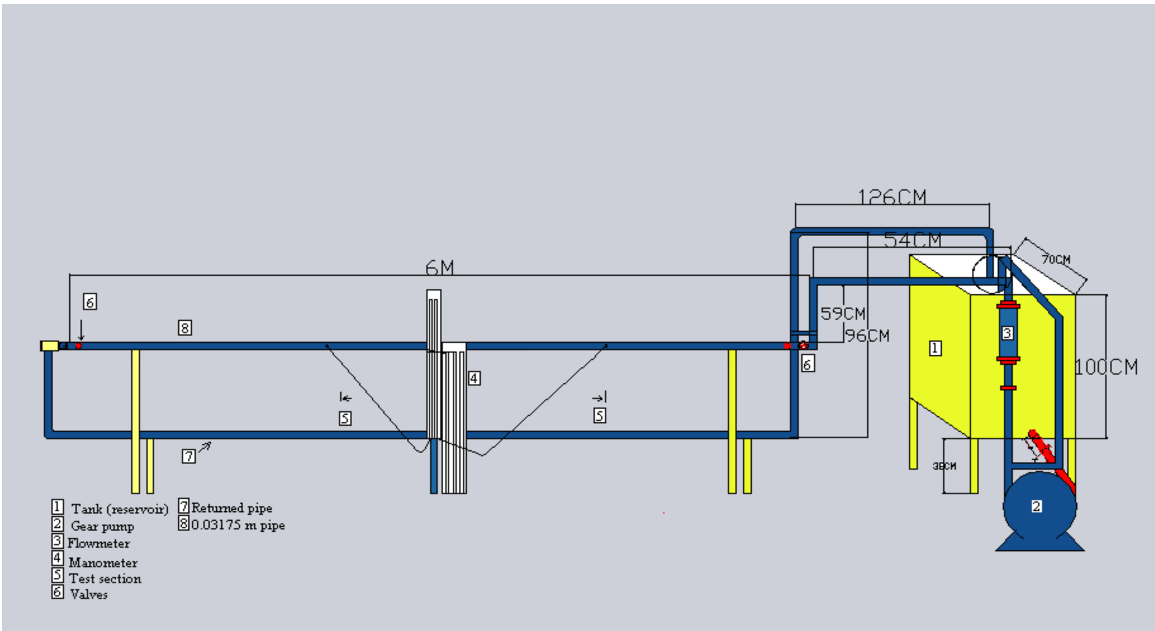

Fig. (1) Schematic diagram for the experimental apparatus

The data of pressure drop decrease is illustrated in fig.2 for polyisobutylene of 2.5 * 10^6 g/mol molecular weight, fig.3 for polyisobutylene of 4.1 * 10^6 g/mol and figs.4 for highest molecular weight additive of 5.9 * 10^6 g/mol. All data are measured at different concentrations, flow rates and constant pipe diameter. The figures show, that the achieved decrease in pressure drop is a function of additive concentration, its molecular weight and fluid flow rate. It was noticed that, the degree of molecular weight is predominate in saving of pressure drop values. Those the highest molecular weight additive gives the lowest pressure drop required for pipelining of gas oil and resulted in more energy saving compared with those of lower molecular weight

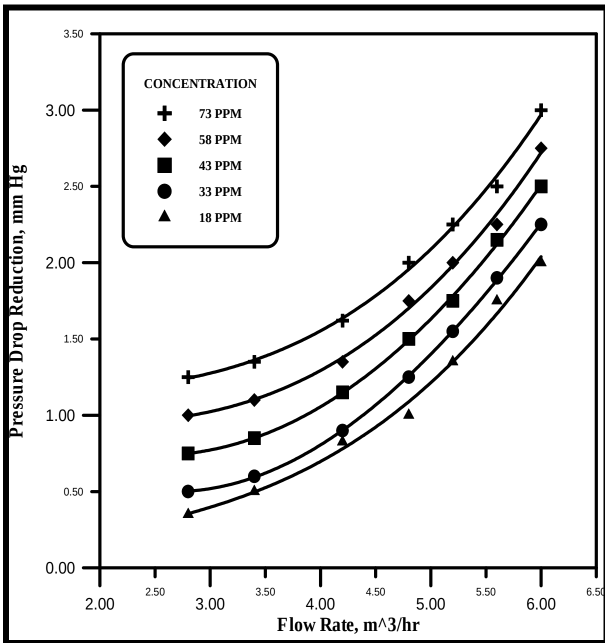

Fig. (2) pressure drop reduction for Oppanol 150 flowing through 1.25 inch I.D pipe

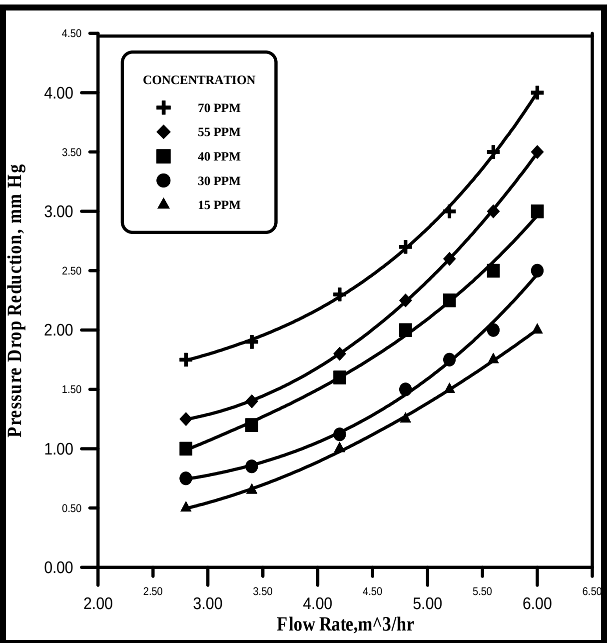

Fig. (3) pressure drop reduction for Oppanol 200 flowing through 1.25 inch I.D pipe

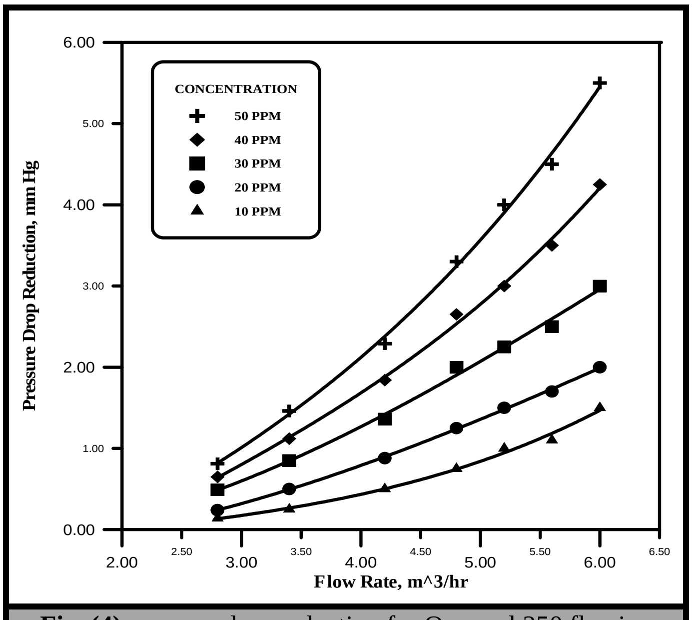

Fig. (4) pressure drop reduction for Oppanol 250 flowing through 1.25 inch I.D pipe

Figures 5, 6 and 7 represent the effect of additive concentrations and solution flow rate on drag reduction effectively for Polyisobutylenes (Oppanol B) of 2.5, 4 and 5.9 millions g/mole molecular weight respectively. The figures show that drag reduction increases as polymer concentration increases for the three different molecular weight polymers. This phenomenon can be explained by the elastic-sublayer model theory of Virk [13]. This sublayer starts to grow with increasing additive concentration

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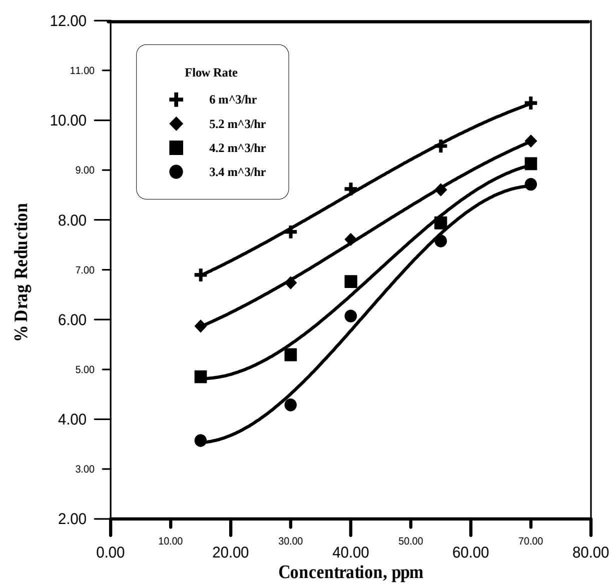

Fig. (5) Effect of concentration on percentage drag reduction for Oppanol 150 through 1.25 inch I.D pipe

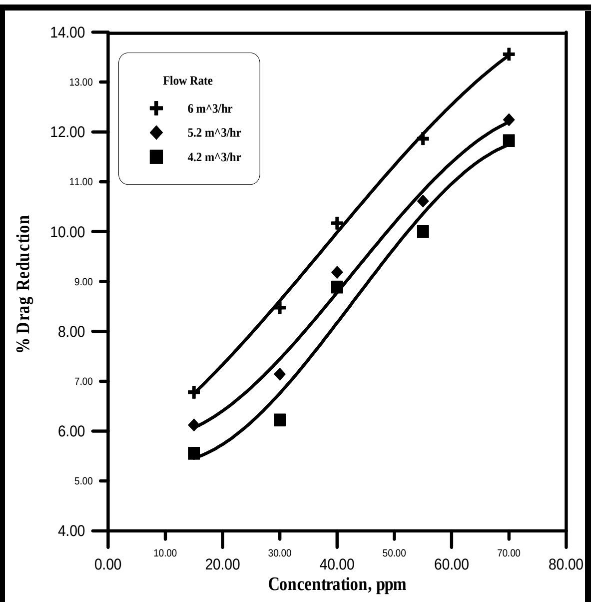

Fig. (6) Effect of concentration on percentage drag reduction for Oppanol 200 through 1.25 inch I.D pipe

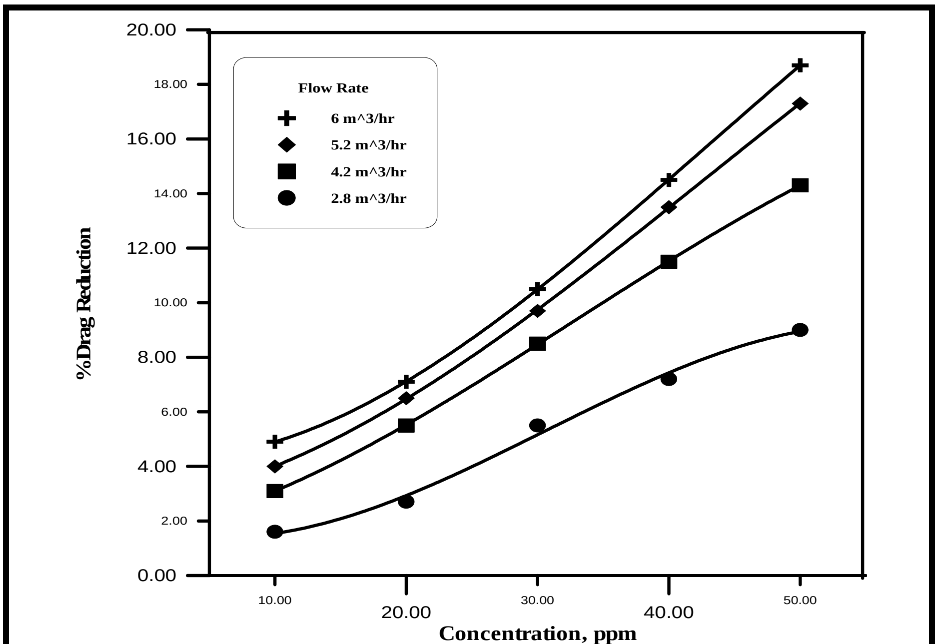

Fig. (7) Effect of concentration on percentage drag reduction for Oppanol 250 through 1.25 inch I.D pipe

It is observed from figures 5-7 that the drag reduction rate increases with flow rate (Reynolds number) for fixed pipe diameter. 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.

This behavior agrees with Berman and his workers [(14), (15)] in which reported that an increase in the strain rate and a decrease in the time scale. Then the elongation reaches a constant level for a given solution and pipe diameter when no other limits are present.

Furthermore, figures 5-7 indicate that the molecular weight of additive is predominate in achieved percentage drag reduction. The effect of molecular weight of Polyisobutylenes additives on the flow performance of gas oil is summarized in tables 1 and 2 for different concentrations and flow rates respectively. Thus, about 19% drag reduction was obtained by using 50 wppm Oppanol B 250 (MW=5.9*10^6 g/mole),while the values for low molecular weight polymers, B 200 (4.1*10^6 g/mole) and B 150 (2.5*10^6 g/mole) were about 11.5% and 9% respectively at the same operating conditions (6 m^3/hr flow rate, 50 wppm concentration, 1.25 inch internal pipe diameter). This observation supported the fact that the dependence of drag reduction efficiency is known to be a function of polymer molecular weight. Since longer and linear polymer chains provide more chance for entanglement and interaction with turbulent flow resulted in reducing of drag forces [(6, 11)].

Table 1 combined effect of polymer molecular weight and concentration on %DR, 1.25 inch pipe diameter, 6.0 m3/hr flow rate

Polymer conc., wppm	Oppanol B 150	Oppanol B 200	Oppanol B 250
	%DR	%DR	%DR
15	6.9	7.0	7.0
30	7.8	8.5	10.5
50	9.5	11.9	18.7

Table 2 combined effect of polymer molecular weight and flow rate on %DR, 1.25 inch pipe diameter, 50 wppm

Flow rate, m3/hr	Oppanol B 150	Oppanol B 200	Oppanol B 250
	%DR	%DR	%DR
4.2	8	10	14.3
5.2	8.6	10.6	17.3
6	9.5	11.9	18.7

It is useful to represent the effectiveness of polyisobutylene of different molecular weights as drag-reducers in the form of Fanning friction factor (*f*) [(2)] as:

$$f = \frac{\Delta P . D / 4L}{\rho . U^2 / 2} \qquad (3)$$

Where:
f = Fanning friction factor.
ΔP= pressure drop, Pa
D = pipe inside diameter, m.
L = distance between the pressure taps, m.
U= velocity, m/s
ρ= density of the fluid, Kg/m^3

Selected samples of the experimental results for friction factor data are illustrated in figures 8. This figure shows that friction factor decreases by increasing the polymer molecular weight, which resulted in an increase of drag-reduction.

It can be noticed that, with low polymer molecular weight is 2.5*10^6 (Oppanol 150), most of the experimental data points, are located at or close Blasuis asymptote, which give an indication that the starting points of the operation are close to that of the standard operation conditions suggested in the literatures. At high molecular weight and high flow rates, the experimental data points are positioned in the direction of lowering friction towards Virk asymptote that represent maximum limits of drag reduction. This give the idea that, to reach such an asymptote, higher molecular weight and Re are needed for each pipe diameter. But, it must be considered that higher concentrations should not affect solvent properties, also by considering the economical costs of raw material of drag reducing agents, therefore it was difficult to reach Virk asymptote without affecting the investigated solvent properties.

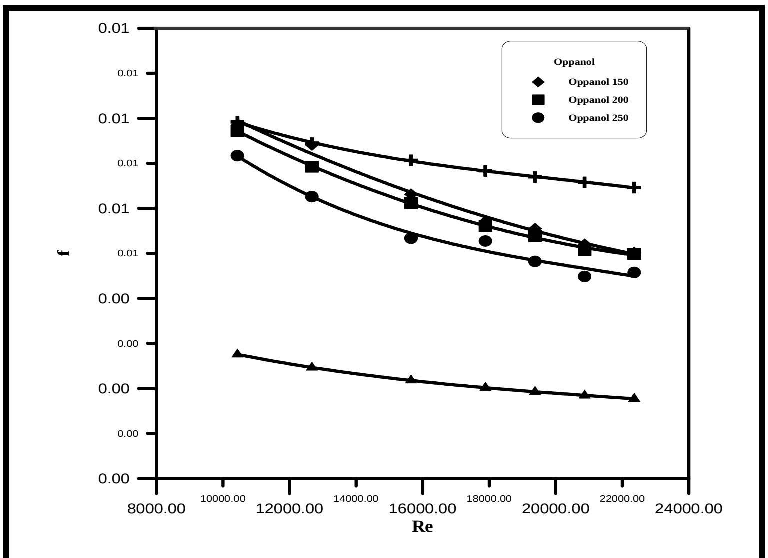

Fig. (8) Friction factor versus Reynolds number at different polymer molecular weights, at 50 wppm concentration through 1.25 inch I.D pipe

The experimental results show, that the drag-reduction efficiency is to be a function of polymer molecular weight, polymer concentration and the degree of turbulence (flow rate). The primary end use of drag reducers is usually to increase the flow rate (throughput increase) without exceeding the safe pressure limits within the flow system.

The evaluation of drag-reduction rate was done experimentally by measurement of pressure drop in a test section of the fully developed flow. It was useful to find correlations to predict the pressure drop values based on flow conditions such as polymeric molecular weight, concentration, flow rate [16].

The dependence of pressure drop reduction (PDR) with molecular weight, polymer concentration and flow rate, is fitted as follows:

PDR=b1+b2*M*Q*(C)^b3+b4*Q^(b5)*(C)^b6* (M)^b7	4

Where:

M = molecular weight in g/mole

C = concentration in wppm

Q = flow rate in m^3/hr

The values of the constants b1, b2 b3, b4, b5, b6 and b7 where give the best fitting of the experimental data were computed by Statica program, as listed in table (3).

Figure (9) show the relation between the observed values of pressure drop reducing taken form experimental data and the predicted values from mathematical correlation. It can be noticed that most points lie at or close to the straight line, which means a good agreement between theoretical and experimental data, with correlation coefficient value of 0.973.

Table (3) Values of the correlations coefficients in equation 4, using 1.25 pipe diameter

b1	1.8309
b2	0.0935
b3	0.3946
b4	- 0.3971
b5	0.5642
b6	0.2331
b7	0.8674
Variance	0.9461
Correlation coefficient	0.973

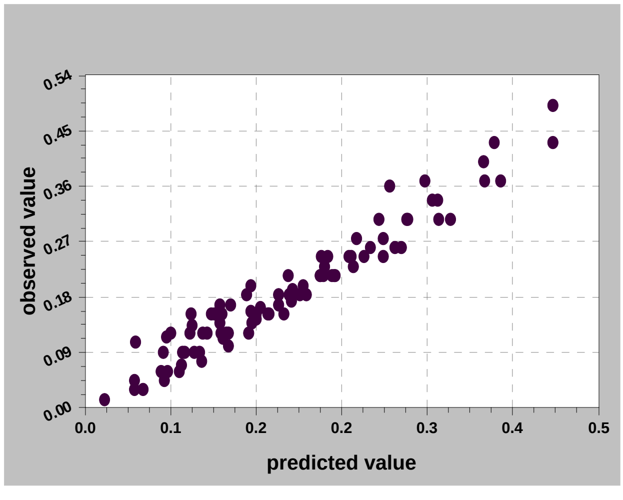

Fig. (9) Predicted versus observed values of pressure drop reducing

Conclusions

1. The three types of polyisobutylene of different molecular weights investigated (B 250, B 200 and B 150) were found to be effective drag reducing agent when used in turbulent gas oil pipelining. For each polymer type, percentage drag reduction was found to increase by increasing the polymer concentration and solution flow rate.
2. It was noticed that, the degree of molecular weight of polyisobutylene polymers is predominate in the rate of drag reduction.
3. The highest molecular weight polyisobutylene B250 treated gas oil shows the greatest degree of flow capacity increase, approaching the maximum drag-reduction asymptote of Virk.

Nomenclature

Symbol	Meaning	Unit
ΔP	Pressure drop	[N/m^2]
D	Pipe inside diameter	m
L	Testing section lenght	m
M	Molecular weight of polymer	g/mole
C	Polymer concentration	ppm
Q	Flow rate	M^3/hr
Greek letters	**Meaning**	**Unit**
f	Fanning friction factor	-
u	Fluid velocity	m/s
ρ	Fluid density	Kg/m^3
Abbreviations		
%DR	Percentage drag reduction	-
PDR	Pressure drop reduction	-

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تأثير الوزن الجزيئي على تقليل الإعاقة الاضطرابي بواسطة بوليمر الايزوبيوتيلين

د. جابر شنشول جمالي
استاذ
قسم الهندسة الكيمياوية/ جامعة النهرين

حيدر موفق توفيق
مدرس مساعد
قسم الهندسة الكيمايوية / جامعة النهرين

الخلاصة:

تم دراسة تقليل الاعاقة الاضطرابي في منظومة جريان مغلقة لزيت الغاز بوجود ثلاث اوزان جزيئية مخلتفة من البولي ايزوبيوتيلين. تم الحصول على الجريان الاضطرابي بواسطة مضخة الازاحة الموجية لتجنب الانحلال الميكانيكي لسلاسل البوليمرية. البوليمرات المستخدمة على شكل محاليل في الريفورميت و تمثل مديات مختلفة للوزن الجزيئي، هي ٢.٩*$١٠^{٦}$ ، ٤.١*$١٠^{٦}$ و ٥.٩*$١٠^{٦}$ غرام/الوزن الجزيئي، بهدف دراسة تأثير الوزن الجزيئي على تقليل الاعاقة و زيادة طاقة الضخ في انابيب نقل زيت الغاز.

تم اختبار تاثير تركيز البوليمرات المظافة بحدود تصل الى ٧٠ جزء بالمليون وزنا، علاوة على سرعة الجريان المتمثلة بعدد رينولدز بحدود ٨٣٤١ الى ٣٥٧٤٧ في انبوب بقطر داخلي ١,٢٥ أنج. تحصل زيادة مستمرة في تقليل الاعاقة بزيادة تركيز البوليمر المضاف، و سرعة الجريان زيت الغاز.

تم حساب معامل الاحتكاك من نتائج العملية لتقليل الاعاقة. تقع قيم معامل الاحتكاك لزيت الغاز الغير معامل باتجاه محاذي بلاسيوس. بينما تتجه قيم معامل الاحتكاك نحو محاذي فيرك عند أضفة بوليمرات تقليل الاعاقة، خاصة للنوع ذي الوزن الجزيئي الاعلى. النتائج العملية تشير بوضوح الى تاثير الوزن الجزيئي العالي على فعالية تقيل الاعاقة.

تم اقتراح معادلات تخمينية لتقدير تأثير معاملات منظومة الجريان، و هي التركيز، سرعة الجريان و اخيرا الوزن الجزيئي على انخفاض تقليل هبوط الضغط. نتائج المعادلات تؤشر الى توافق كبير بين قيم هبوط الضغط المستحصلة عمليا و المحسوبة من المعادلات التخمينية بنسبة اعلى من ٩٧%.