SILICA POWDER AS DRAG REDUCING AGENT IN GASOIL FLOWING IN PIPELINES SYSTEM

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ABSTRACT

In this study the effect of the presence of a drag reducing agent (DRA) on the pressure drop in co-current horizontal pipes carrying flow of gas oil is investigated. An experimental set-up is erected. The tested fluid was gas oil and Silica powder with 50 ppm (ppm-part per million), 100 ppm, 200 ppm and 300 ppm weight concentration of Silica powder. The test section of the experimental set-up is consisted of three different pipe diameter and testing section length. The experimental was dealing with 0.5 inch, 1.0 inch, 1.5 inch ID and 0.5m long, 1.0m long and 1.5m long. Gas oil also was pumped with five different fluid flow rates which is for each pipe diameter have a differ values of volumetric flow rate setting. The percent drag reduction (%DR) is calculated using the obtained experimental data, in presence of the DRA. The results show that addition of DRA could be effective up to some doses of DRA. Not only that, with smaller pipe diameter, performances of drag reduction occur is much better than larger pipe diameter. A %DR of about 72 is obtained for some experimental conditions. For the various powder concentrations versus percent of drag reduction, the maximum drag reduction occurs was about 72.73% in 300 ppm concentration level.

KEYWORDS: Powder; Silica powder; Drag reduction; Additives; Turbulent flow; Pipelines; Eddies

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1. INTRODUCTION

Drag reduction as a phenomenon occurs where adding certain amount of drag reducing agent, such as polymer, surfactant or fiber. From addition of that agent, it causes a dramatic frictional drag reduction(1) . The drag reduction effects are very important in the industrial application. The application of drag reducers has been in the Trans-Alaska Pipeline, which is a major U.S oil pipeline. They desired discharge of an additional million barrels of crude oil per day was accomplished by the addition of polymers rather than by constructing additional pumping stations (2) .

Drag reducers have been applied can give a lot of benefits such as in pipeline systems. It can save pumping power, reducing energy consumption, increasing the flow rate, decreasing the size of pumps and many more in turbulent pipe flow systems.

The drag reduction agents solution flows behave viscoelastic characteristics. The most notable elastic property of the viscoelastic polymer or surfactant solutions is that stress does not immediately become zero when the fluid motion stops, but rather decays with some characteristic time that is the relaxation time, which can achieve seconds and even minutes(1). The existence of fluid viscoelasticity is known to give rise to unusual secondary flows and to produce anomalous drag reduction in turbulent pipe flow(3). In their work, the additives were carrying out experimental test to study the mechanism of additive induced drag reduction.

Among the investigation of this field,(2) was previously doing numerical and experimental test with using cationic surfactant additives Cetyltrimethyl ammonium chloride (CTAC). They used this CTAC solution because of their long-life characteristics, can be used as promising drag-reducers in district heating and cooling systems. In their study they performed both numerical and experimental tests for a 75 ppm CTAC surfactant drag-reducing channel flow.

2. DRAG REDUCTION DEFINITION

Drag reduction can defined is a flow phenomenon by which small amount of an additives, for instance a few parts per million (ppm), can greatly reduce the turbulent friction of a fluid. Aim of the drag reduction is to develop the fluid mechanical efficiency using active agents that known as drag reducing agent (DRA). In single and multiphase flow, drag reduction (%DR) can defined as the ratio of reduction in the frictional pressure difference when the flow rates are held constant to the frictional pressure difference without DRA, and then multiplied by 100, as shown in Eq. (1) (4).

$$\% \, DR = [(\Delta P_b - \Delta P_a) / \Delta P_b]*100 \quad . \quad \textbf{(1)}$$

In this equation 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.

3. DRAG REDUCTION AGENT (DRA)

The effect of drag reduction in turbulent flows by additives was apparently discovered by Toms in 1948, and has been known since then as the Toms phenomenon. It is the effect of reduced drag in turbulent flow of a low concentration fibrous additive suspension, in comparison to the drag in turbulent flow of the pure solvent [5]. The addition of small concentrations of high molecular weight polymer to gas oil or other solvent can produce large reductions in frictional pressure drop for turbulent flows past a surface, leading to the possibility of increased pipeline capacities and faster ships.

Fibers are long cylinder like objects with high length to width ratio. They oriented themselves in the main direction of the flow to reduce the drag [4, 6] stated that fiber suspension occurs in a wide variety of natural and man-made materials. The investigation of microstructure of fiber suspension has received much attention because the mechanical, thermal and electrical properties of the corresponding fiber composite are highly sensitive to the orientation distribution and spatial configuration of fibers. Such suspension has complicated rheological properties that are different from those of the suspending fluid, even at very low concentrations.

Actually, most of the surfactants at higher concentrations can cause a change of the physical properties of the surfactant solutions and also cause strong surface films between adjacent molecules. Basically, when increasing surfactant solution concentration, the surface tension will decrease, and the dynamic surface tension is usually higher than equilibrium surface tension at a fixed concentration. Higher solution temperature results in lower surface tension in both equilibrium and dynamics conditions [3].

4. DRAG REDUCTION MECHANISM

In a review of the literature of Yasuo Kawaguchi [7] . the mechanism of additive induced drag reduction has not been clearly described. For polymer solutions, two theoretical explanations are given. One was proposed by Lumley [8,9], who postulated that the increased extensional viscosity due to the stretching of randomly coiled polymers tends to dampen the small eddies in the buffer layer and thickens the buffer layer, to give rise to the drag reduction. Lumley emphasized that drag-reduction occurs only when the relaxation time of the solution is larger than the characteristic time scale of the turbulent flow. The other important theory was proposed by De Gennes [10], who criticized the earlier scenario that used extensional viscosity, and argued that the elastic energy stored in the macromolecules causes drag-reduction. For surfactant solutions, generally, the super-order network structures made up of rod-like micelles show elasticity, and cause drag-reduction. Nevertheless, these explanations are qualitative.

Direct numerical simulation (DNS) has been used to quantitatively analyze the turbulence transport mechanism. With DNS, the instantaneous flow structures near the wall can be calculated accurately, which are difficult to measure precisely in experiments. The instantaneous extra stress associated with the deformation of macromolecules/network structures can be calculated which has not yet been directly measured in experimental conditions. The quantitative data obtained by DNS are helpful in analyzing the mechanism of drag-reduction. Moreover, in contrast to experiments, the effects of various physical properties can be easily isolated and studied by numerical simulations. Main conclusions drawn from previous DNSs on the drag-reducing flow caused by additives are summarized below. Orlandi (11) and DenToonder (12) carried out DNS using extensional viscosity models for a channel, and a pipe flow, respectively. Their results qualitatively agree with most experimental observations.

On the other hand, the inelastic characteristic of such extensional models cannot examine the onset phenomenon, an important feature of drag-reducing flow caused by additives. Sureshkumar (13) and Dimitropoulos (14) performed direct numerical simulations for a fully developed turbulence channel flow by using viscoelastic models (the Finitely-Extensible-Nonlinear-Elastic dumbbell model (FENE-P) and the Giesekus models), and verified Lumley's hypothesis that drag reduction is primarily an effect of the extension of the polymer chains where the increase in the extensional viscosity leads to the inhibition of turbulence-generating events. They also proposed a criterion for the onset of the drag-reduction.

Angelis and et.al.(15) further confirmed the ability of the FENE-P model to reproduce most of the essential effects of polymers in dilute solutions on the wall turbulence. Min and et.al.(16) studied the role of elastic energy in turbulence drag-reduction caused by polymer additives using an elastic Oldroyd-B model (is a simple linear viscoelastic model for dilute polymer solutions, based on the dumbbell model). Yu and Kawaguchi (17) studied the effect of the Weissenberg number , (s the ratio of the relaxation time of the fluid and a specific process time), on the turbulence flow structure using a Giesekus model (extra-stress tensor).

5. MATERIAL AND METHODS

Fifteen set of experimental work with 75 runs were carried in a built-up close loop liquid circulation system to examine all the effects of the variables investigated.

5.1FLOW SYSTEM DESCRIPTION

The flow systems as shown in Figure 1 consist of reservoir tank, pipes, valves, pumps and differential pressure manometer are constructed to present the current investigation requirements. The reservoir tank was supported with two exit pipes connected to centrifugal pumps. The first exit pipe was connected to the main centrifugal pump which delivers the fluid to the testing sections while the other is connected to the other centrifugal pump for deliver excess solvent to reservoir tank. Three PVC pipes of various inside diameters 0.5, 1.0 and 1.5 inch were used in constructing the flow system. A complete closed loop piping system was build. Piping starts from the reservoir tank through the pump, reaching a connection that splits the pipe into two section pipes. 1 set of Baumer Differential Pressure Manometer Gauge were used to detect the pressure drop in pipelines with minimum reading is 0.01 bar and maximum differential pressure manometer reading up to 0.25 bar. In order to measure the flow rate of fluid in pipelines, Ultraflux Portable Flow Meter Minisonic P has been used. This ultrasonic flow meter measurement was sensitive with small changes in flow rate as low as 0.001 ms^{-1} can be detected.

5.2 SILICA POWDER

The additive used in this study is Silica powder; the purpose behind using this powder is to overcome the solubility condition that must be there for any additive to be introduced as drag reducing agent, knowing that the silica is insoluble either in aqueous or oil Medias. The chemical composition of the silica used is CaO3 which is white powder with particle size of 40 µm, bulk density of 0.6 to 0.8 g/cm^3 and Sp. Gravity 2.5 to 2.7.

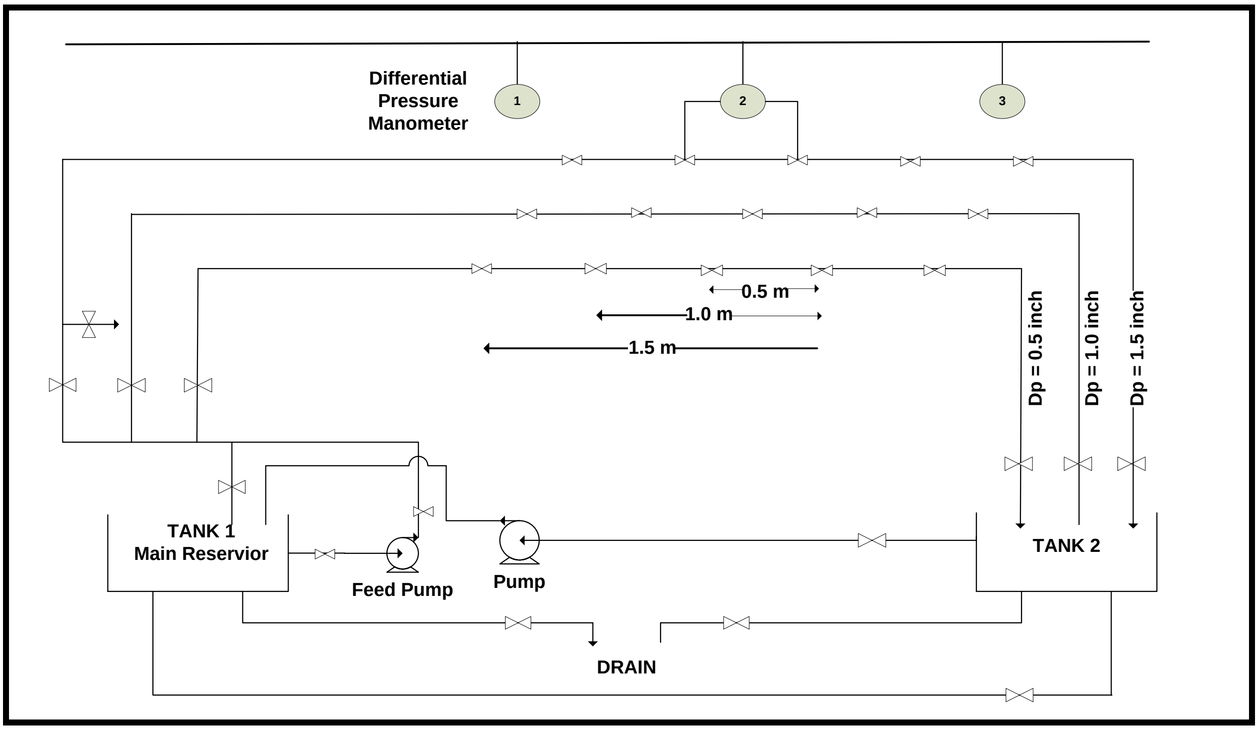

Figure 1: A schematic diagram of the experimental apparatus.

6. EXPERIMENTAL PROCEDURE

The main purpose of this work is studying the drag reduction in the pipeline systems. This experiment doing is to investigate the effect of the different values of Silica powder concentrations, liquid flow rate, pipe diameter and length of pipes in order to get the pressure drop of the fluid.

The test section of the experimental set-up was consisted of 0.5, 1.0 and 1.5 inch diameter pipe with testing length of 0.5, 1.0 and 1.5 m. Before the addition of the Silica powder into the main reservoir tank, the data of pressure drop versus flow rate of gas oil were first recorded for all pipes. The powder addition to the flow systems were 50, 100, 200 and 300 ppm. These solutions were prepared in beakers before adding to the main tank. Each experimental solution was mixed 24 hours in main tank before the experiment starts in order to ensure the Silica powder is well mixed with the gas oil. For every powder concentration, the operation begins when the pump starts delivering the solution through the testing section. The solution flow rate was set with different value for each pipe diameter that shown in Table (1) by controlling it from the bypass section. Pressure drop readings are taken for each flow rates. This procedure was repeated for each powder concentration.

Table 1: Experimental flowrate used

Pipe Diameter, ID (inch)	Flowrate, Q (m^3/hr)	Velocities (m/sec)
0.5	0.2, 0.4, 0.6, 0.8, 1.0	0.44, 0.87, 1.31, 1.75, 2.19
1.0	0.5, 1.0, 1.5, 2.0, 2.5	0.27, 0.54, 0.82, 1.09, 1.37
1.5	3.0, 3.5, 4.0, 4.5, 5.0	0.73, 0.85, 0.97, 1.09, 1.21

7. EXPERMENTAL CALCULATION

i. Percentage drag reduction calculation

Percentage of drag reduction is calculated from the pressure drop data using the equation as follows:

$$(\%\ \mathrm{DR}) = \left[\frac{\Delta P_b - \Delta P_a}{\Delta P_b}\right] \times 100 \quad \textbf{(1)}$$

In this equation 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.

ii. Velocity and Reynolds Number calculation

The average velocity (V) and Reynolds number (Re) were calculated using the solution volumetric flow rate readings (Q), density (ρ), viscosity (μ) and pipe diameter (D), for each run as follows:

$$\mathrm{V} = \frac{\mathrm{Q}\ (\mathrm{m}^3/\mathrm{hr})}{\mathrm{A}\ \ (m^2\ ) * 3600\,\mathrm{s}} = \frac{\mathrm{m}}{\mathrm{s}} \quad \textbf{(2)}$$

$$\mathrm{Re} = \frac{\rho \mathrm{VD}}{\mu} \quad \textbf{(3)}$$

$$\boldsymbol{A = \frac{\pi}{4} D^2}$$

8. Results and discussions

A. Effect of adding powder concentration to the pipe length section

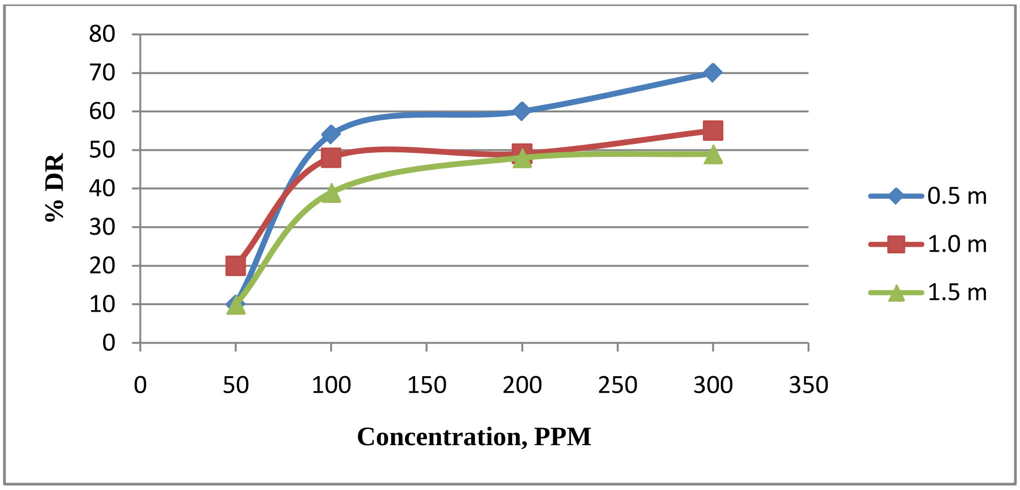

Fig 2: Effect of powder concentration versus %DR flowing through 1.0 inch pipe diameter with Re = 24355.34

The performance of powder as drag reducing agent (Silica powder) as a function of powder concentration due to the different pipe length is shown in Figure 2. The investigation was doing on 1.0 inch pipe diameter and 24355.34 of Reynolds Number. The Silica powder concentrations used for this experiment were 50, 100, 200 and 300 ppm. From this figure, clearly we can see that an increasing of additive concentration can give great impact to the performance of percentage drag reduction. Not only have that, the smaller pipe length gave more % DR compare to the bigger one. On the other hand, the results shows that the maximum drag reduction can be achieved until 72.73% for 0.5 m pipe length. The others drag reduction were varies between 9% and 63%. When used of 1.0 m pipe length, the highest % DR is 60% compare to the 1.5 m is 50%.

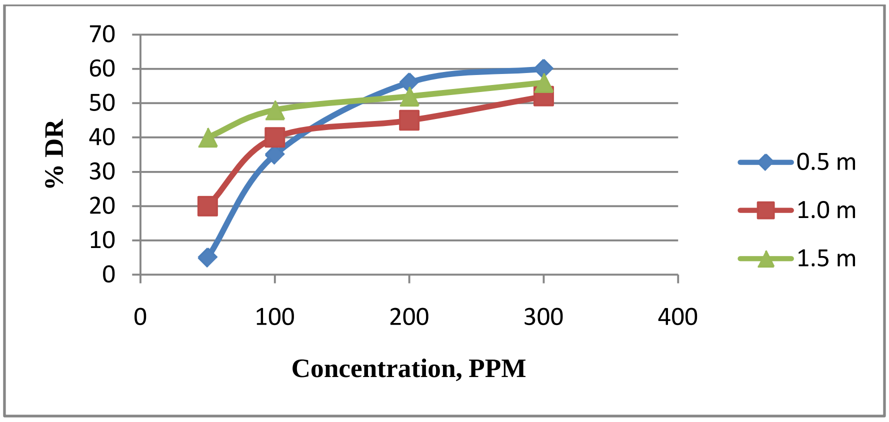

Fig 3: Effect of powder concentration versus %DR flowing through 1.0 inch pipe diameter with Re = 40592.234

For Figure 3, the data was plotted between powder concentrations versus percentage of drag reduction. This figure is quite similar with Figure 2, which means that, this figure used

40592.234 of Reynolds Number different with the first one that used 24355.34. The same objective want to obtain that is to investigate of % DR on the different test section length, but here have some difference with using the bigger number of Reynolds Number. From this figure, % DR is increased due to the decreasing of test section length. When range of powder concentration between 50 to 100 ppm, the 0.5 m pipe length not give good recital of % DR, but when used 200 and 300 ppm, % DR is higher than others. The maximum drag reduction that achieved was 64.3%.

B. Effect of adding powder concentration to the internal pipe diameter

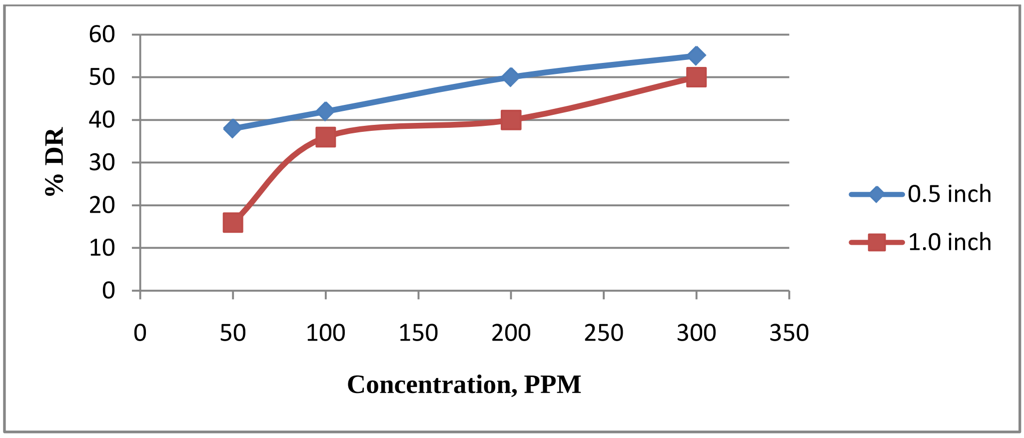

Fig 4: Effect of powder concentration versus %DR flowing through 1.0 m pipe length with 1.0 m^3/hr fluid flowrate

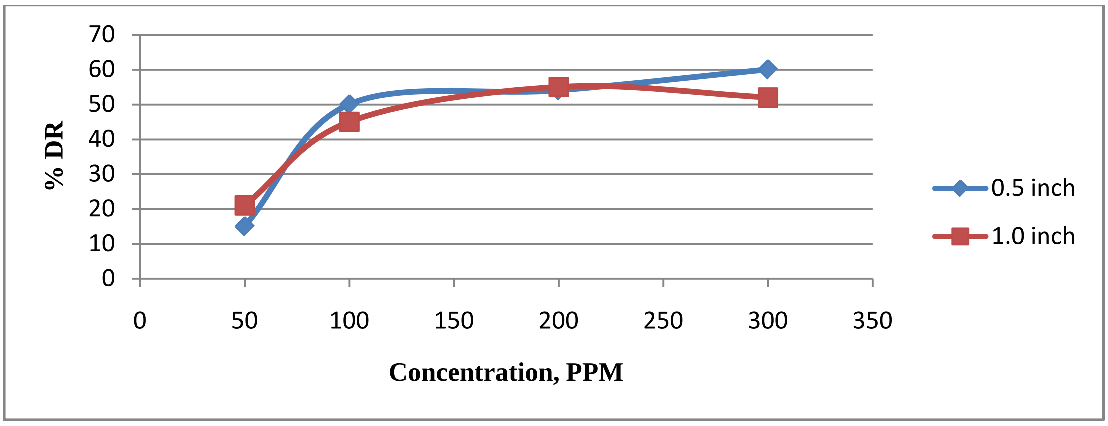

Fig 5: Effect of powder concentration versus %DR flowing through 1.5 m pipe length with 1.0 m^3/hr fluid flowrate

In Figure 4 and 5 shows the graph of plotted data between Silica powder concentrations versus percentage of drag reduction. From this examined, it proved that when the comparison between smaller and larger internal pipe diameter make, the smaller one was give higher

%DR than the larger. Noted that the profile pattern for first graph of 0.5 inch pipe diameter, when range of powder concentration about 50 to 300 ppm, %DR were 38% until 61%.

C. Effect of the additive concentration to the various Reynolds Number

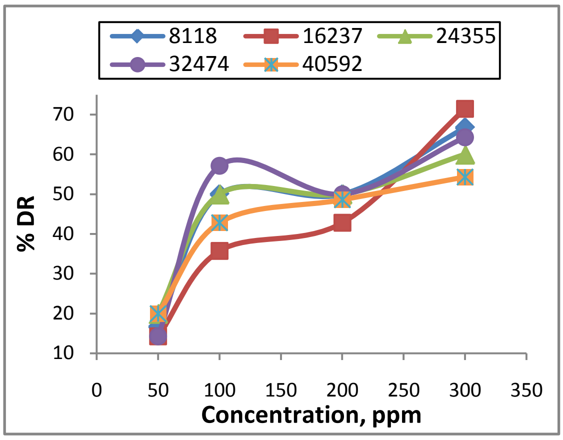

Fig 6: Effect of powder concentration on %DR flowing through 1.0 inch pipe diameter and 1.0 m pipe length

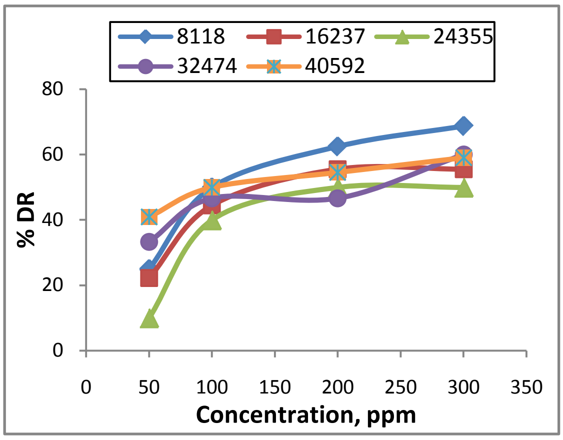

Fig 7: Effect of powder concentration on %DR flowing through 1.0 inch pipe diameter and 1.5 m pipe length

In Figures 5,6 and 7, the percent of drag reduction is plotted versus powder concentration with different pipe length for various Reynolds Number. It is observed that, by adding a low concentration of the powder, one can find a reduced pressure drop per unit length at the same flow conditions. Not only have that, the percent of drag reduction increases when the powder concentration is increase. For Figure 6, the maximum percent of drag reduction that can be achieved was 71.4% for Figure 6 and 68.8% for Figure 7.

CONCLUSIONS

The drag reduction effects are very important in the industrial application especially in pipeline systems. Because of the turbulent flow always occur in pipeline system, it will cause the pumping stations that should be install is increase in order to improve the fluid flows. So, with using an additive of powders that acts as drag reducing agents, the drag reduction phenomenon will occurs. The most importance part in this research is to investigate the phenomenon of drag reduction in the pipeline systems.

The drag reduction behavior of Silica powder has been studied. From the investigational work doing, by adding a small amount of powder concentration, it will cause great impact to the performance of fluid flow in turbulent flow. Based on the graph plotted above, it shows a better look pattern. So, it was proven that Silica powder is a great drag reducing agent in a fluid turbulent flow.

Basically, when increasing the concentration of powder, the percent of drag reduction also increase in all conditions of examined research. Besides that, drag reduction also increases with the smaller pipe diameter compare with the larger pipe because of the degree of turbulence. In comparison between lesser and larger pipe length, the lesser pipe length give more drag reduction percentage because the pressure drop occur is low.

Tables

Table 2. Effect of powder concentration versus %DR flowing through 1.0 inch pipe diameter with Re = 24355.34

Concentration PPM	%DR		
	0.5m	1.0m	1.5m
50	10	20	10
100	54	48	39
200	60	49	48
300	70	55	49

Table 3. Effect of powder concentration versus %DR flowing through 1.0 inch pipe diameter with Re = 40592.234

Concentration PPM	%DR		
	0.5m	1.0m	1.5m
50	5	20	40
100	35	40	48
200	56	45	52
300	60	52	56

Table 4. Effect of powder concentration versus %DR flowing through 1.0 m pipe length with 1.0 m^3/hr fluid flowrate

Concentration PPM	%DR	
	0.5”	1.0”
50	38	16
100	42	36
200	50	40
300	55	50

Table 4. Effect of powder concentration versus %DR flowing through 1.5 m pipe length with 1.0 m^3/hr fluid flowrate

Concentration PPM	%DR	
	0.5”	1.0”
50	15	21
100	45	50
200	54	55
300	60	52

REFRENCES

1. Feng-Chen Li, Yasuo Kawaguchi, Bo Yu, Jin Jia Wei, Koichi Hishida, *Experimental Study Of Drag-Reduction Mechanism For A Dilute Surfactant Solution Flow*, International Journal of Heat and Mass Transfer 51 (2008) 835-843.
2. Bo Yu, Fengchen Li, Yasuo Kawaguchi, *Numerical And Experimental In Investigation Of Turbulent Characteristics In A Drag-Reducing Flow With Surfactant Additives*, International Journal of Heat and Fluid Flow 25 (2004) 961-974.
3. Lixin Cheng, Dieter Mewes, Andrea Luke, *Boiling Phenomena With Surfactants And Polymeric Additives: A State-Of-The-Art Review*, International Journal of Heat and Mass Transfer 50 (2007) 2744-2771.
4. D.Mowla and A.Naderi, *Experimental Study Of Drag Reduction By A Polymeric Additive In Slug Two-Phase Flow Of Crude Oil And Air In Horizontal Pipes*, Chemical Engineering Science 61 (2006) 1549 – 1554.
5. I. Sher and G. Hetsroni, *Amechanistic Model Of Turbulent Drag Reduction By Additives*, Chemical Engineering Science 63 (2008) 1771 – 1778.
6. J.Z. Lin, Z.Y. Gao, K. Zhou, T.L. Chan, *Mathematical Modeling Of Turbulent Fiber Suspension And Successive Iteration Solution In The Channel Flow*, Applied Mathematical Modelling 30 (2006) 1010–1020.
7. Yasuo Kawaguchi, Takehiko Segawa, Ziping Feng, Peiwen Li, *Experimental Study On Drag-Reducing Channel Flow With Surfactant Additives - Spatial Structure Of*

Turbulence Investigated By PIV System, International Journal of Heat and Fluid Flow 23 (2002) 700 –709.

8. Lumley, J.L. 1969 Drag reduction by additives. Ann. Rev. Fluid Mech. 1, 367{384.
9. Lumley, J.L. 1973 Drag reduction in turbulent ow by polymer additives. J. Poly. Sci. Mac. Rev. 7, 263 - 290.
10. De Gennes, P. G. 1990 Introduction to Polymer Dynamics. Cambridge University Press.
11. Orlandi, P. 1995 A tentative approach to the direct simulation of drag reduction by polymers. J. Non-Newtonian Fluid Mech. **60**, 277–301.
12. Den Toonder, J.M.J., Hulsen, M.A., Kuiken, G.D.C. and Nieuwstadt, F.T.M., 1997, "Drag Reduction by Polymer Additives in a Turbulent Pipe Flow: Numerical and Laboratory Experiments", J Fluid Mech, Vol.337, pp. 193-231.
13. Sureshkumar, R., Beris, A. N. & Handler, R. A. 1997 Direct numerical simulation of the turbulent channel of polymer solution. Phys. Fluids 9, 743-755.
14. Dimitropoulos, C.D., Sureshkumar, R. and Beris, A.N., 1998, "Direct numerical simulation of viscoelastic turbulent channel flow exhibiting drag reduction: effect of the variation of rheological parameters" J Non-Newt Fluid Mech, vol. 79, pp. 433-468.
15. De Angelis, E., Casciola, C.M. and Piva, R., 2002, "DNS of wall turbulence: dilute polymers and self-sustaining mechanisms". Computers & Fluids, Vol.31, pp. 495-507.
16. Min, T. & Choi, H. 2001 E_ect of spatial discretization schemes on numerical solutions of viscoelastic uid ows. J. Non-Newtonian Fluid Mech. 100, 27 -47.
17. Yu B., Li, F.C. and Kawaguchi Y., 2003. Numerical and Experimental Investigation of Turbulent Characteristics in a Drag – reducing flow with surfactant Additives. 3rd International Symposium on turbulent and Shear flow Phenomena, Sendai 3, 971-976.

تقليل الاعاقه لجريان زيت الغاز في منظومه انابيب بايتخدام مسحوق السليكا

الخلاصة

في هذه الدراسة تم التحقق من تأثير وجود عوامل تقليل الاعاقة على هبوط الضغط في منظومة جريان افقية لمائع زيت الغاز. تم اعداد منظومة مختبرية لتلك الدراسة حيث كان المائع زيت الغاز مع مسحوق السليكا بتركيز 50 و 100 و 200و 300 جزء بالمليون تركيز وزني لمسحوق السليكا. و كان مقطع الاختبار هو انابيب بثلاثه اقطار مختلفة وكانت 0.5 و 1 و 1.5 انج و بطول 0.5 و 1.0 و 1.5 متر طول. تم ضخ المائع بخمسة سرع مختلفة لكل قطر من الاقطار و بالتالي بمعدلات جريان حجمية مختلفة.

تم حساب نسبة التقليل بالاعاقة (DR%) بالاعتماد على النتائج العملية بوجود عامل تقليل الاعاقة و اظهرت النتائج بان تلك الاضافات كانت فعاله بتراكيز معينه من المضافات كما تبين ان تقليل الاعاقة في الاقطار الصغيرة اوضح من الاقطار الاخرى وتم الحصول على نسبة تقليل اعاقة بمقدار 72% في بعض التجارب . وان اعلي نسبة اعاقه كانت 72.73% بتركيز 300 جزء بالمليون .