Modern Applied Science; Vol. 12, No. 1; 2018
ISSN 1913-1844 E-ISSN 1913-1852
Published by Canadian Center of Science and Education

Drag Reducer Selection for Oil Pipeline Based Laboratory Experiment

Leksono Mucharam[1], Silvya Rahmawati[1] & Rizki Ramadhani[1]

[1] Petroleum Engineering Department, Institut Teknologi Bandung, Indonesia

Correspondence: Silvya Rahmawati, Petroleum Engineering Department, Institut Teknologi Bandung, Ganesha St. Nr 10 Labtek IV, West Java, Bandung, Indonesia Tel: 62-22-2506282. E-mail: sdr@tm.itb.ac.id

Received: December 13, 2017 Accepted: December 21, 2017 Online Published: December 28, 2017

doi:10.5539/mas.v12n1p112 URL: https://doi.org/10.5539/mas.v12n1p112

The research is financed by P3MI Research Fund ITB Bandung – Indonesia.

Abstract

Oil and gas industry is one of the most capital-intensive industry in the world. Each step of oil and gas processing starting from exploration, exploitation, up to abandonment of the field, consumes large amount of capital. Optimization in each step of process is essential to reduce expenditure. In this paper, optimization of fluid flow in pipeline during oil transportation will be observed and studied in order to increase pipeline flow performance.

This paper concentrates on chemical application into pipeline therefore the chemical can increase overall pipeline throughput or decrease energy requirement for oil transportation. These chemicals are called drag reducing agent, which consist of various chemicals such as surfactants, polymers, nanofluids, fibers, etc. During the application of chemical into pipeline flow system, these chemicals are already proven to decrease pump work for constant flow rate or allow pipeline to transport more oil for same amount of pump work. The first application of drag reducer in large scale oil transportation was in Trans Alaskan Pipeline System which cancel the need to build several pump stations because of the successful application. Since then, more company worldwide started to apply drag reducer to their pipeline system.

Several tedious testings on laboratory should be done to examine the effect of drag reducer to crude oil that will be the subject of application. In this paper, one of the testing method is studied and experimented to select the most effective DRA from several proposed additives. For given pipeline system and crude oil type, the most optimum DRA is DRA A for pipeline section S-R and for section R-P is DRA B. Different type of oil and pipeline geometry will require different chemical drag reducer.

Keywords: pipeline, drag reduction agent (DRA), laboratory experiment

1. Introduction

One of the most important issues in oil and gas transportation is the existence of turbulence flow in pipeline. Turbulence condition can be described as irregular and erratic movement of fluid when nonlinear inertial effect is superior than viscous effect, generally the fluctuated properties are velocity, temperature, and density. Turbulence flow to happen, energy is needed in order of the inertial effect to dominate over viscous effect. Therefore, the existence of turbulence implies great amount of energy lost to form turbulence leaving less energy to support fluid flow. This creates inefficiency in fluid pipeline transformation as the fluid flow could be faster for same energy input or require less energy for same flowrate.

Limiting turbulence formation can increase energy efficiency as well as increase the throughput of pipeline transportation. Because it is not economical to reduce turbulence by lowering flowrate as it limits field productivity, a better way is invented, that is the use of certain chemical called Drag Reduction Agent or DRA. Drag Reduction Agent is a long chain additive with heavy molecular weight. The effect of DRA application is called Drag Reduction which defined as increase of pumpability of fluid due to addition of small amount of additive into the fluid system in the pipeline.

Phenomenon of drag reduction was first observed by British chemist Toms in 1948. Thirty years later the addition of DRA to pipeline system was first applied by Trans Alaskan Pipeline System in July 1st, 1979. This application proved to be successful in increasing pipeline throughput and eliminating the need for additional pump stations. TAPS thus able to operate near to the optimal production rate of Prudhoe Bay of more than 1.5 MMBBL per day. Since then, the application of drag reducing agent have become popular worldwide. However, until today there is no particular DRA developed for every type of crude oil. Before application of DRA to pipeline system, some testing should be conducted to test the compatibility of prospected DRA to fluid flowing inside the pipeline. This paper discusses one of the selection method to obtain best DRA for a certain case using laboratory observation. The DRA is choosen based on criteria such as: increasing oil flow in the pipeline and optimum drag reduction.

2. Method

This study was done by conducting laboratory experiment using flow loop system. The flow loop system was tested using water to determine turbulence phenomenon.

2.1 Drag Reduction

Drag reduction is a phenomenon in which the turbulence of flow inside pipeline significantly decreased as the effect of addition of small ammount of additives. Drag reduction can result on reduction of pressure drop along pipeline system and at a time also reduce energy requirement for fluid flow. There are formulas to measure drag reduction perceived by fluid flow as presented in Equation (1) and Equation (2).

Percent of Drag reduction (%DR):

$$\%DR = \frac{\Delta P - \Delta Pp}{\Delta P} \times 100 \quad (1)$$

Throughput Increase (%TI):

$$\%TI = \left[\left(\frac{1}{1 - \frac{\%DR}{100}}\right)^{0.55} - 1\right] \times 100 \quad (2)$$

Percent of drag reduction indicated the performance of DRA, but do not reflect the output of the pipeline as it is calculated by %TI. Studies that have been done in the past concluded that drag reduction only happen in turbulence flow region because there was no significant change in pressure drop observed in laminar flow region. Hoyt (1989) also observed that drag reduction have maximum value which is when additional concentration of additive no longer resulting increase in percent of drag reduction.

2.2 Type and Mechanism of DRA

There are three major type of drag reducing agent that frequently used in pipeline transportation system, which included;

- Polymer based DRA
- Surfactant based DRA
- Nanofluid

Other than those, some additive also observed to have drag reducing properties such as fibres, microbubbles, and compliant coating. Each type of DRA has different mechanism in reducing drag within the pipeline system. Although still effectively established, drag reducing agents are believed to work in some manner such as turbulence suppression, extension of laminar range limit to higher Reynolds Number, near wall flow modification, and friction reduction in fully developed turbulence flow. Polymer additives that used as drag reducing agent must be in a form of a long-chained polymer which has heavy molecular weight. The polymer chain in fluid flow dampens the forming of eddie current and as the result turbulence is greatly reduced.

Surfactant additives work by forming bilayer sheet micelle. Hydrophobic part of micelle avoids contacts with polar molecule of crude oil. On the other hand, hydrophylic part of micelle contacts with polar molecule allowing the hydrophobic part of micelle to concentrate in the center of bilayer micelle formation. Micelle function in similar manner as polymer chain that dampens the formation of eddie current in fluid flow.

Nanofluid is a relatively new additive used as drag reducer. Nanofluid is believed to work in different way with polymer and surfactant additives. Nanofluid, such as Nano-SiO_2, work by filling the crevices of pipe wall resulting reduction of pipe relative roughness.

2.3 Drag Reduction using Polimer

Polymer works as drag reducing agent by dampening the formation of eddie current so turbulence can be highly reduced, as concluded by several researchers. It has also observed that polymer performance affected by several factors, such as: effect of concentration, channel size and geometry, molecular weight, chain flexibility, and flow rate.

2.3.1 Effect of Concentration

Concentration was observed proporsionally related with drag reduction until maximum drag reduction is reached. This happens due to the concentration of additives increase more chains of polymer and dampening the formation of eddie current. Maximum value of drag reduction is reached when addition of polymer concentration no longer increase performance of drag reduction or even reduce the performance.

2.3.2 Effect of Channel Size and Geometry

Effect of channel size is still in controversy, different researcher provided different answer with different logical and scientific expalanation. Karami and Mowla (2012) investigated that drag reduction decrease as diameter of channel increase. The explanation for this is that pipe with smaller diameter has larger degree of turbulence (Re) due to larger relative roughness (ϵ/D) compared to pipe with larger diameter. Higher degree of turbulence means that addition of polymer will result on higher decrease of pressure drop thus the effect of drag reduction is more significant.

In terms of channel geometry, some researches concluded that the effect of drag reduction is more prominent in straight pipe rather than in curved pipe. It has also been observed that radius of curvature of the pipe has significantly effect on delaying the onset of drag reduction and reducing the impact of drag reducing agent applied. Radius of curvature also reduces maximum drag reduction that can be achieved by polymer application.

2.3.3 Effect of Molecular Weight

General understanding based on results of some research concluded that drag reduction increased by increasing molecular weight, heavier polymer potentially has better ability to absorb and prevent formation of eddie current that composed turbulence.

2.3.4 Effect of Chain Flexibility

Flexibility of polymer chain is attributed to its ability to reduce drag. Flexible chain will serve as better cushion to absorb and dampen the formation of turbulence flow by reducing eddie current generation.

2.3.5 Effect of Chain Flowrate

Flowrate of fluids in pipeline is directly related ro Reynold number (Re) of fluid flow. Increasing flowrate means increase in degree of turbulence, allowing drag reducer to produce bigger margin of drag reduction. Mowla and Naderi (2008) studied the effect of polymer concentration on the percentage of dragreducer effectiveness for four types of drag reducer agent that presented in Figure 1.

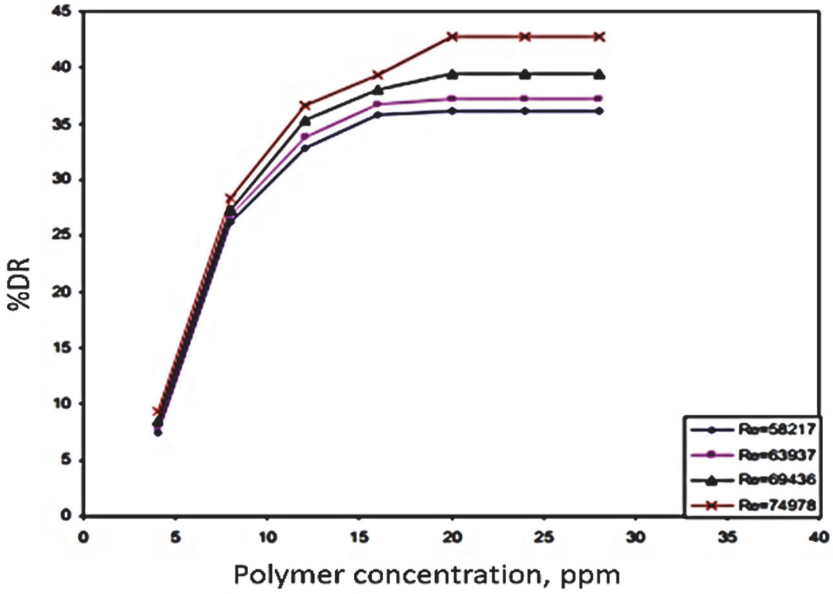


Figure 1. Comparison of DR performance at different flowrate (Mowla and Naderi, 2008)

2.4 Drag Reduction Using Surfactant

Surfactant additives reduce drag inside the pipeline by forming micelles as results of interaction between polar and nonpolar molecule of surfactant and oil. These micelles will help reduce flow turbulence by functioning as shock absorber that reduce formation of eddie current. There are several factors that affect surfactant performance as DRA that discussed below.

2.4.1 Effect of Concentration

Percent of drag reduction increase along with increase of surfactant concentration as discussed by Abdul-Hadi and Khadom (2013) and depicted in Figure 2. Higher concentration of surfactant inside fluid flow provides more micelle structure that can reduce formation of turbulent flow. Behaviour of surfactant concentration is the same as polymer concentration, at some point of concentration, drag reducing performance of surfactant will reach its maximum value.

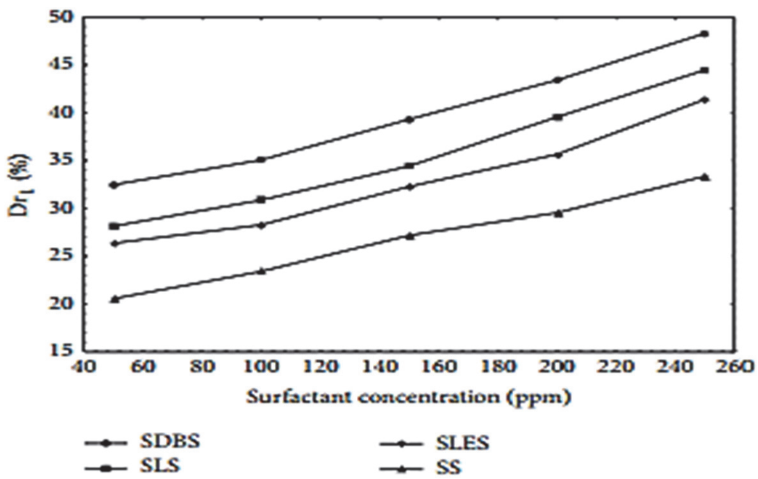


Figure 2. Effect of surfactant concentratio on precent of drag reduction (Abdul-Hadi and Khadom, 2013)

2.4.2 Effect of Diameter

Effect of diameter or channel size on drag reduction still not clearly established, several researchers believe that drag reduction is higher in small pipe because of higher degree of turbulence due to larger relative roughness

(ϵ/D). Figure 3 shows the effect of pipe diameter on drag reduction. There is also other point of view that drag reduction is higher in larger pipe diameter because eddie current formed in larger pipe absorb greater amount of energy.

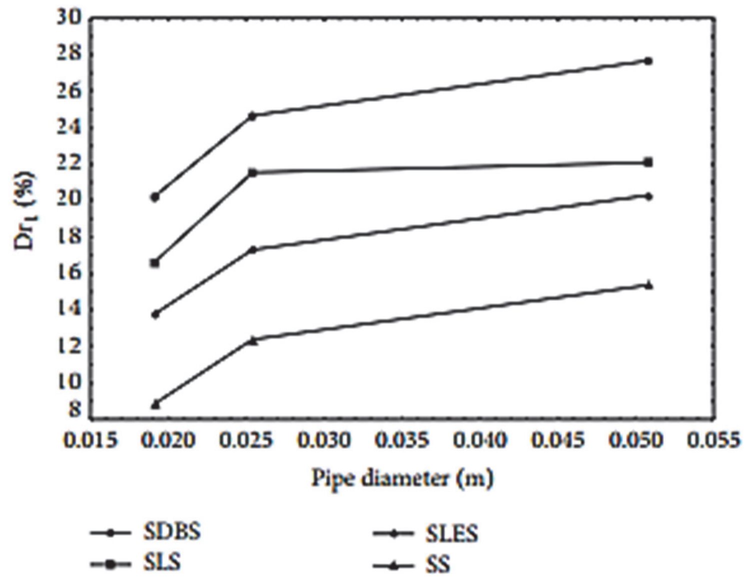


Figure 3. Effect of pipe diameter on drag reduction (Abdul-Hadi and Khadom, 2013)

2.4.3 Effect of Flowrate

Performance of drag reducer observed to be proportional to flowrate of fluid flow. Increase of fluid flow rate results on increase of degree of turbulence (Re) as shown in Figure 4. Higher turbulence allows drag reducer to create greater margin of drag reduction.

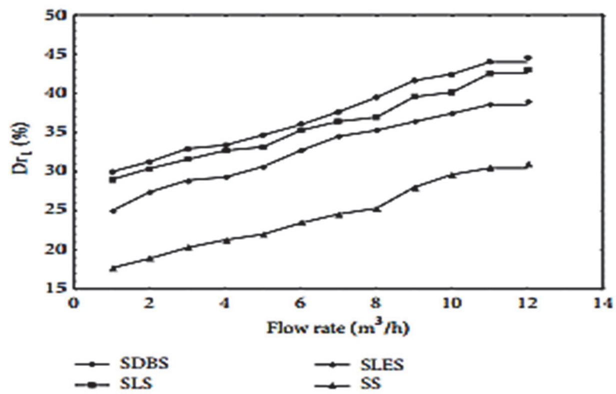


Figure 4. Effect of flowrate on drag reduction (Abdul-Hadi and Khadom, 2013)

2.5 Drag Reduction Using Nanofluid

Nanofluid contains particles that are very small in size, to the degree of nanometer. These particles are suspended in base fluid as colloidal suspension. Nanofluids works differently compared to surfactant and polymer as drag reducer. Nanofluid reduce drag inside the pipeline using mechanism called surface modification. Nanoparticle of the fluid reside in crevices along pipeline inside wall, making the pipeline a smoother conduit for fluid flow. Smooth pipe wall will affect turbulence as it will reduce Reynold Number (Re) by lowering relative roughness of the pipe. The most common nanofluid applied as drag reducer is Nano-SiO_2. Nano-SiO_2 is relatively cheap and easier to find and proven to give good result as drag reducer.

2.5.1 Effect of Concentration

Concentration is an essential factor in nanofluid application that should be monitored carefully. Amount of nanofluid that should be applied to a pipeline system depends on roughness of pipe inner surface. As concentration increase, drag reduction will also increase as the surface of the pipe get smoother. Maximum drag reduction will be reached when all crevices in pipeline wall completely filled with nanofluid particle. Minimum value of drag reduction is observed when drag reduction effect monitored firstly as concentration of nanofluid applied increase. At very small concentration, nanofluid will not provide any drag reduction because the nano-particle in the flow is not enough to fill pipe roughness. Figure 5 shows the effect of nanofluid concentration and Reynold number on percentage of drag reduction.

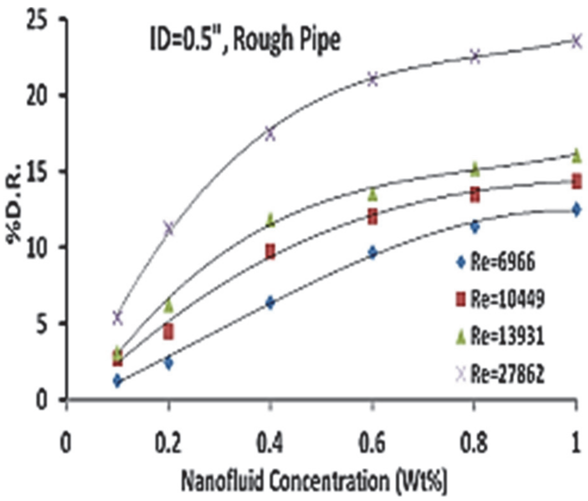


Figure 5. Effect of nanofluid concentration and Reynold Number on percentage of drag reduction (Pouranfard, Mowla, and Esmaeilzadeh, 2013)

2.5.2 Effect of Pipe Roughness

Nanofluid drag reducer performs better in rougher pipe. Effect of drag reduction observed at same concentration of nanofluid but gets higher as pipe roughness increase, indicated by the value of Reynold Number.

2.5.3 Effect of Flowrate

Higher flowrate will increase degree of turbulence in fluid flow inside a pipeline system. The performance shows similarity with surfactant and polymer application this condition gives the drag reducer the ability to reduce drag by larger margin thus higher drag reduction achieved.

2.5.4 Effect of Pipe Diameter

Similar with drag reduction by polymer and surfactant. Drag reduction increases as pipe diameter decrease as presented in Figure 6. Small diameter pipe has higher Reynolds number as results of higher relative roughness of the pipe.

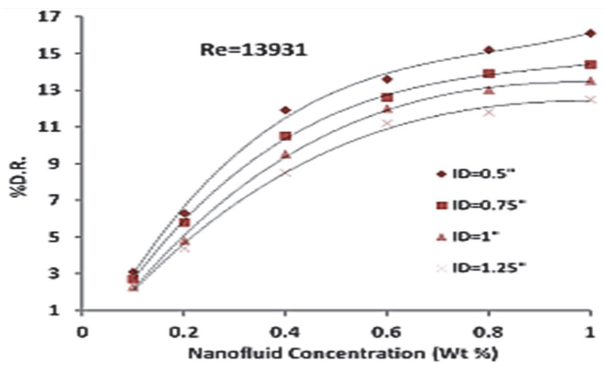


Figure 6. Drag reduction performance in different pipe diameter (Pouranfard, Mowla, and Esmaeilzadeh, 2013)

2.5.5 Effect of Multiphase Flow

In nanofluid application as drag reducer, observed that drag reduction in multiphase flow is higher than in single-phase flow presumably because of reduction of surface tension by nanoparticle along with surface modification that reduce dissipation rate due to turbulence flow. This effect can be enhanced by adding sodium dodecyl sulphate (SDS) to fluid flow. Figure 7 shows the effect of multiphase flow on drag reduction.

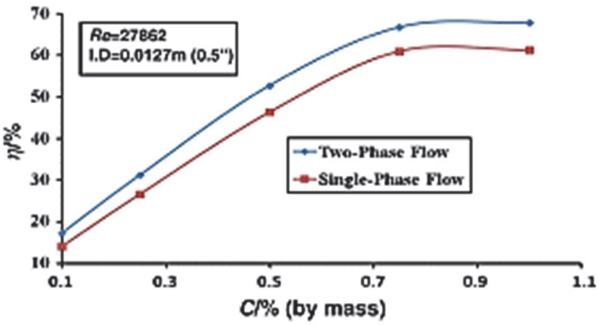


Figure 7. Effect of multiphase flow on drag reduction (Pouranfard, Mowla, and Esmaeilzadeh, 2013)

2.6 Challenge on Drag Reducer Agent Application

During the application of DRA in continuous turbulent flow inside pipeline, there are two major problem suffered by drag reducer related to degradation, those are mechanical degradation and dry out. Mechanical degradation occurs as result of interaction with flow turbulence or during extreme agitation when fluid pass through centrifugal pump. Dry out happens when solvent of drag reducer evaporates leading to precipitation of drag reducing agent, this eliminates the effect of drag reduction.

Polymer drag reducer is very susceptible to degradation as the polymer molecule can permanently break relatively easily when subjected to extreme shear stress, this leads to reduction in drag reducing capability of polymers. There are several factors that affect polymer resistance to mechanical degradation which are molecular weight and molecular weight distribution of polymer, temperatue, polymer concentration, degree of turbulence, polymer preparation, and flow geometry. Effect of temperature to polymer degradation is observed to be very complex because there is critical temperature at which the behaviour of temperature toward degradation shifts. Below this critical temperature, degradation delayed as temperature increases and above the critical temperature, degradation increase with increase in temperature.

Chemical additives applied as drag reducer is well known to be toxic as they are non-biodegradable, mostly the oil-soluble ones. On the other hand, water soluble additives are less toxic. Sound disposal strategy should be made to prevent chemical pollution on the environment.

2.7 Consideration During DRA Selection

Until now there is no certain type of drag reducer that is applicable for all type of oil. Prior to drag reduction application some detailed test should be done to determine which kind of additive is suitable for the crude oil. As result of numerous research, there are several general knowledges about drag reducer that can be considered during period of selection:

- DRA should be effective at low concentration. Addition of drag reducer into pipeline fluid flow is carried out continuously so it needs drag reducer in large amount. Drag reducer that can be effective at low concentration help reduce capital cost for DRA application. In long term despite the concentration needed is low, volume of DR required will still large due to continuous application.
- Crude oil in question should not cause problem in refinery process. Increasing pipeline throughput becomes useless when existing facilities can not handle the crude.
- Drag reducer should have molecular weight larger than one million grams per mole.
- Drag reducer should be shear degradation resistance up to certain level.
- Drag reducer should have good solubility in pipeline fluid.
- Drag reducer should be able to resist heat, chemical, and biological degradation.

2.8 Laboratory Experiment

This experiment is based on actual field pipeline system in X-field located in Indonesia and conducted using crude oil sample from that source. The pipeline and field owner wanted to increase field production without replacing the existing pipeline with new bigger pipeline. For this purpose, the field owner gathered DRA sample from three producers. Figure 8 shows the field pipeline arrangement. The sample was taken from crude production of P station and S station. Both samples then tested using three drag reducing agents with undisclosed composition. For easier management of the data the DRAs then called DRA A, DRA B, and DRA C.

The test was run in a flow loop system apparatus which consist of a cylindrical oil chamber (ID = 6 in, h = 45 cm), rotary jet pump, compressor (7.5 HP 420 L 12 bar), analog pressure gauges (0-35 psi), ball valves, and pipelines (ID=0.5 in) which separated by pressure guages into two sections, section 1 is 3 meters and section 2 is 4 meters. Detailed illustration of equipment arrangement can be seen from Figure 9. The first step of this test is to circulate the sample that will be tested in the flow loop system. Then the small amount of crude is taken from the chamber to prepare the DRA solution with certain concentration of DRA. The prepared sample is then added to the circulation. After several minutes when the pressure gauges are stabilized, the data is then collected by taking notes of pressure reading from each gauge and measuring the flowrate. After each run, the system is cleaned using detergent and diesel oil to wash of remained crude and DRA inside the pipeline and the pump. When the system already dried the next test can be done with same procedures.

Assumptions during testing are applied as the following:

- Homogeneity of each solution from each test is the same.
- DRA mixed properly in the circulated solution when the measurement is taken.
- Each test is conducted in one phase flow with only crude oil solution inside the pipe.
- The test was conducted in atmospheric condition of 1 atm and 27 degree Celcius.

The heating of waxy oil is done properly so the temperature is the same at each part of the oil.

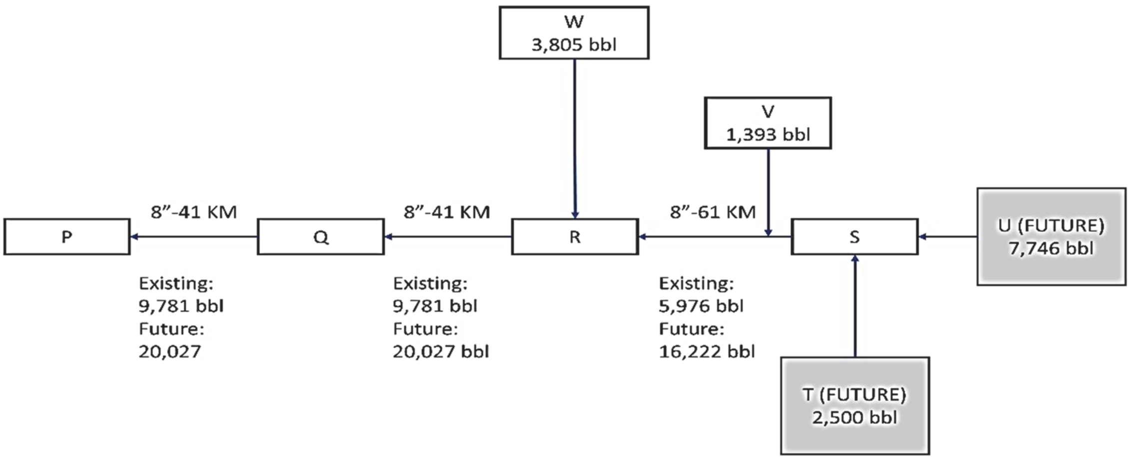


Figure 8. Schematic of pipeline arrangement

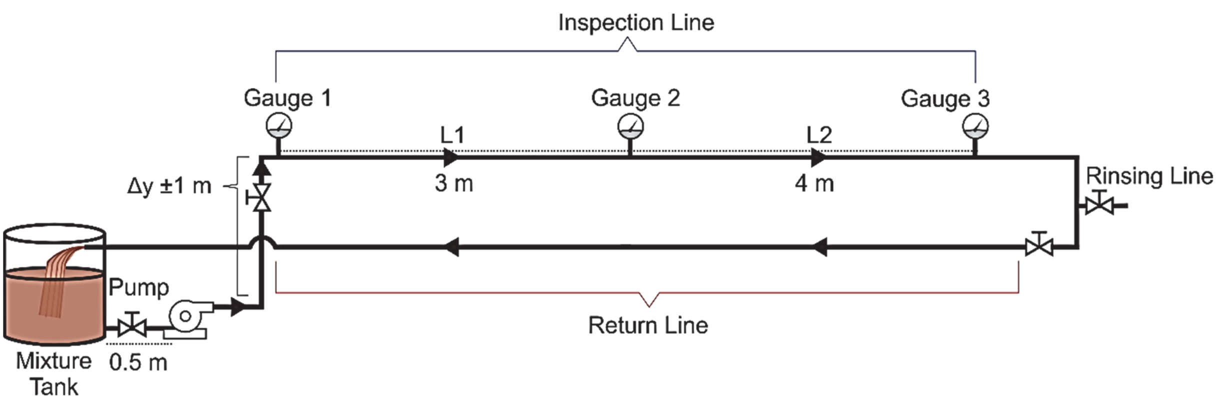


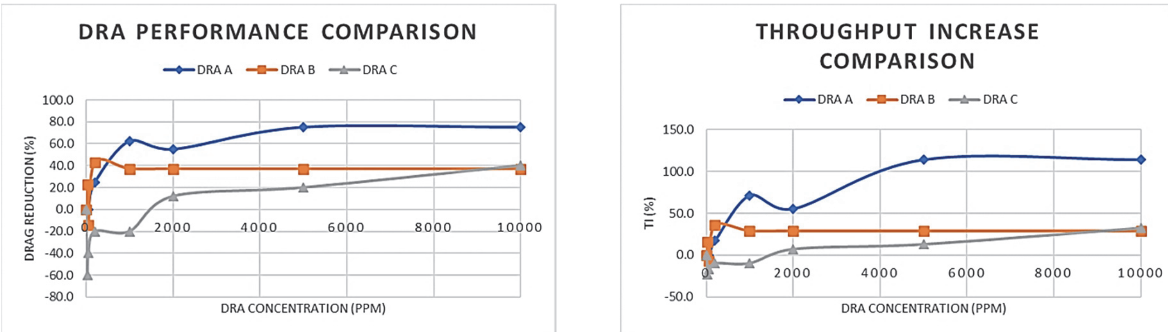
Figure 9. Flow loop system

3. Results

The data obtained from the experiment is in the form of pressure at each measurement points and flow rate of each mixture of DRA and crude oils. From these data, drag reduction caused by certain DRA and it is performance through the length of the pipeline can be observed. The performance of DRA is calculated using equation (1) and (2).

3.1 Crude Sample S (S-R section)

Flow loop test on sample S using three DRA (DRA A, DRA B, and DRA C) shows in Figure 10.

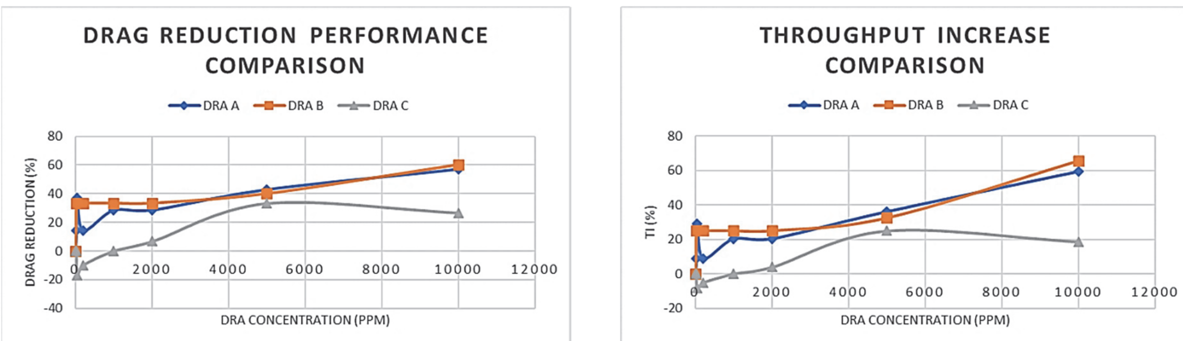


(a). Drag reduction on sample S (b). Throughput increase on sample S

Figure 10. Drag reduction results for sample S (S-R section) using three different DRA types

3.2 Crude Sample P (R-P section)

Flow loop test on sample P using three DRA (DRA A, DRA B, and DRA C) shows in Figure 11.



(a). Drag reduction on sample P by DRA C (b). Throughput increase on sample P by DRA C

Figure 11. Drag reduction results for sample P (R-P section) using three different DRA types

4. Discussion

Figure 10 and Figure 11 depicts the behaviour of drag reducer in accordance with changes in concentration and pipe section for corresponding crude sample. Roughly it can be observed that increase in DRA concentration yields increase in drag reduction. From most of the graphs can also be seen concentration of DRA where drag reduction no longer occurs. By comparing total drag reduction and throughput increase produced by corresponding DRA, the most suitable additive can be selected. For pipeline section S-R, DRA A clearly shows dominant effect compared to the other two DRAs. DRA A gives maximum drag reduction of nearly 80% and can increase pipeline throughput by 114%. As for pipeline section R-P DRA selection is a bit difficult as DRA A and DRA B show relatively similar performance, can be seen from the graph. But considering the requirement that drag reducer should be able to work effectively at low concentration, DRA B excels than DRA A because it produce higher drag reduction at lower concentration. Because it is impractical to change DRA mid way through the pipe line, DRA A is more favorable to be applied in both section because overall DRA A shows better performance compared to DRA B.

In accordance with the research purposes. From this study can be concluded that:

1. Drag reducer application to oil flow results on decrease of pressure drop inside the pipeline. In this study, change in pressure drop is marked by the value of drag reduction.
2. Increase in additive concentration tends to increase drag reduction experienced by oil flow inside the pipeline. In some of the measurement, maximum value of drag reduction can be observed.
3. In pipeline section S-R, DRA A shows the best performance, followed by DRA B and DRA C respectively. For pipeline R-P, DRA B slightly better than DRA A.
4. The optimum DRA for use in pipeline section S-R is DRA A and for section R-P, the optimum DRA is DRA B.

Acknowledgments

We would like to thank P3MI research fund from Institut Teknologi Bandung for funding the research.

References

Abubakar, A., Al-Wahaibi, T., Al-Wahaibi, Y., Al-Hasmi, A. R., & Al-Ajmi, A. (2014). Roles of Drag Reducing Polymer in Single- and Multiphase Flows. *Chemical Engineering Research and Design,* ELSEVIER.

Ali, A. A., Hadi, Anees., & Khadom, A. (2013). Studying the Effect of Some Surfactants on Drag Reduction of Crude Oil Flow. Chinese Journal of Engineering. *Hindawi Publishing Corporation.*

Anees, A., Khadom, A., & Abdul-Hadi, A. (2014). Performance of Polyacrylamide as Drag reduction Polymer of Crude Petroleum Flow. *Ain Shams Engineering Journal.*

Burger, E. D., Munk, W. R., & Wahl, H. A. (1982). Flow Increase in the Trans Alaska Pipeline Through Use of A Polymeric Drag-Reducing Additive. *Journal of Petroleum Technology.*

Karami, H., & Mowla, D. (2012). Investigation of the effects of various parameters on pressure drop reduction in crude oil pipelines by drag reducing agents. *Journal of Non-Newtonian Fluid Mechanics, 177-178*, 37-45. https://doi.org/10.1016/j.jnnfm.2012.04.001

Mowla, D., & Naderi, A. (2008). Experimental Investigation of Drag Reduction in Anuular Two-Phase Flow of Oil and Air. *Iranian Journal of Science & Technology.*

Pouranfard, A. R., Mowla, D., & Esmaeilzadeh, F. (2014). *An Experimental Study of Drag Reduction by Nanofluids in Slug Two-Phase Flow of Air and Water Through Horizontal Pipes. Chinese Journal of Chemical Engineering,* ELSEVIER.

Pouranfard, A. R., Mowla, D., & Esmaeilzadeh, F. (2013). An Experimental Dtudy of Drag Reduction by Nanofluids Through Horizontal Pipe Turbulent Flow of a Newtonian Fluid. *Journal of Industrial and Engineering Chemistry,* ELSEVIER.

Symbol

DR	Drag reduction
DRA	Drag reducing agent
%DR	Percent of drag reduction
%TI	Throughput increase
ΔP	Pressure drop without DRA
ΔPp	Pressure drop with DRA