Chemistry International 9(4) (2023) 128-133

International Scientific Organization
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Investigation of the chemical composition and efficiency of drag reducing agent in a multiphase oil-water-gas system

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ARTICLE INFO

Article type:
Research article
Article history:
Received February 2023
Accepted July 2023
October 2023 Issue
Keywords:
Export line
Friction
Pressure gradient
Reynolds number

ABSTRACT

Different concentrations of drag reducing agents (DRA) were used to envisage the efficiencies of DRAs in a multiphase oil-water-gas system. DRAs with weight concentrations of 25.0, 50.0, 75.0 and 100.0 (%) obtained from α-β unsaturated hexadecene polymer, vegetable oil, sodium palmitate and polyacrylate (pour point modifier), respectively were used. The oil-water mixture combined in a tee section flows into a 1 m^3 mixing tank made of carbon steel where carbon IV oxide stored in a 30-ton liquid receiver was introduced into the system at a constant pressure of 30 barg and then, fed into the bottom of the mixing tank simulating a multiphase oil-water-gas mixture. The pressure gradient along the multiphase oil-water-gas 10.00 cm PVC pipeline was determined without the DRA as a control and then, with different concentrations. The pressure gradients for the DRA weight concentrations of 25.00, 50.00, 75.00 and 100.00 (%) were 7.57, 5.71, 3.98 and 0.77 barg, respectively, the efficiency factors (E_{DRA}) were 0.57, 0.70, 0.75 and 0.92 respectively, the liquid densities were 0.8778, 0.8892, 0.9154 and 0.9331 respectively and the liquid velocities were 1.50, 0.80, 0.60 and 0.10 m/s, respectively. Higher the weight concentration of the DRA, the lower the pressure gradient along the discharge line of the travelling fluid, the higher the drag reducing ability of the DRA which is reflected in the %DRA and E_{DRA}. The flow distribution and slug characteristics of DRA concentrations were also determined using the Reynolds number and fanning friction factors. The DRA with the highest concentration of 100.00 % had a Reynolds number and fanning friction factor of 5.2831 and 0.0580, respectively, while the least concentration of 25.00 % had a Reynolds number and fanning friction factor of 0.3314 and 0.5788. The fanning friction factor represents the disturbance, friction or turbulence along the export line and higher values represents higher drag and friction along the export line.

Capsule Summary: In a simulated multiphase oil-water gas system, different concentrations of DRA reduced the pressure gradient along the export line travelled by the transported fluid. The higher the concentration of the DRA, the lower the pressure gradient and the higher the drag reducing ability of the DRA.

Cite This Article As: T. N. Chikwe and L. C. Osuji. Investigation of the chemical composition and efficiency of drag reducing agent in a multiphase oil-water-gas system. Chemistry International 9(4) (2023) 128-133.
https://doi.org/10.5281/zenodo.8127646

INTRODUCTION

The rising demand for crude oil as a means of foreign exchange for most nations of the world as well as the diversified use of petroleum products to power several engines have made it imperative to boost crude oil production to necessitate an increase in the gross yield within a period (Nesyn et al., 2018). Drag reducing agents (DRA) or drag reducing polymers are liquid chemical components introduced into crude oil expedition lines with the aim of reducing the frictional disturbance within the line thereby increasing the smooth undisturbed flow of the fluid. DRAs were first discovered by Toms in 1947, He discovered a reduction in pressure gradient for a given liquid velocity after adding DRA. The interaction between the crude and the walls of the expedition line causes a great deal of turbulence which drags the oil back thereby creating a drag force capable of reducing the pressure of the crude along the line (Cheng et al., 2015). Addition of DRA reduces the turbulence arising from the interaction between the crude oil and the walls of the expedition line. The higher the turbulence within the expedition line, the higher the fictional force exerted on the crude which in turn reduces the laminar flow of the crude within the line (Hidema et al., 2018).

The gross production of the crude oil is negatively imparted from the reduction of the laminar flow arising from the turbulence between the crude oil and the walls of the expedition line. DRAs were not originally designed for multiphase systems of oil-water-gas mixtures however due to the formation of water in old wells it has become imperative to extend the use of DRA from just single-phase oil-gas mixtures to multiphase systems of oil-gas-water mixtures (Abubakar et al., 2014). The use of DRA to lower the pressure gradient in single phase liquids (oil and gas) over a long distance has been very helpful in boosting crude oil production in recent years. The use of DRA in the oil and gas industry provides a wide range of benefits ranging from increased production without any mechanical modification or cannibalization, reduction of operating cost such as pumping power, reduction of pipeline pressure while maintaining through put as well as resolution of some refinery challenges such as loading and unloading operations through the increase of daily crude oil production (Shao et al., 2002).

The use of DRA is advantageous in terms of design for new systems for instance DRA helps in the reduction of pipeline diameter as well as capital costs in pump/pumping station. Owing to the fact that the molecular structure of DRAs cannot withstand high shear forces generated by centrifugal or positive displacement pumps, they are usually injected downstream the pumping stations (Gu et al., 2017). Characteristics of the crude has a great deal of impart on the potency of the DRA. Crude oil viscosity, molecular structure of oil, flow velocity which indicate a dependence on the Reynolds number as well as ability of the DRA to disperse in the crude determines the efficiency of the DRA, hence a DRA that produces a desired impart with a certain crude may not be effective with other crudes (Hidema et al., 2018). Having established the impact of the crude on the effectiveness of the DRA, the aim of this study therefore is to investigate the composition and efficiency of DRA in a multi-phase oil-water-gas system and by extension on production and export.

MATERIAL AND METHODS

Sample collection and preparation

Olefin polymers obtained from α-β unsaturated hexadecene monomer was used in the preparation of the DRA used for this study. The polymer was prepared by polymerizing the monomer in the presence of a Ziegler-Natta system made up of titanium chloride, an electron donor and an alkyl aluminum cocatalyst. The polymer was then dispersed in a suitable vegetable oil with a pour point of +3 ^{0}C to -2 ^{0}C serving as a carrier. The choice of vegetable oil emanates from the fact that it is not harmful to the hydrocarbon and it is environmentally friendly. A stabilizing agent of 2 weight% calculated from the weight of the monomer was also introduced to control the dispersion of the monomer within the carrier (vegetable oil), prevent agglomeration and control the overall viscosity of the DRA. Soapy substance obtained from the reaction between sodium hydroxide and fatty acid are the most preferred stabilizing agents in DRA. A typical example is shown in Figure 1 in the reaction between a fatty acid (triglyceride) and sodium hydroxide to form a stabilizing agent (sodium palmitate) for DRA and glycerol as a byproduct. Polyacrylate was also introduced as a Pour point modifier. The α-β unsaturated hexadecene and polyacrylate are shown in Figure 2-3, respectively. The % concentration of the DRA is calculated from the weight% of the individual constituents. Different tests were carried out to investigate the impact of different concentrations of DRA in a multiphase oil-water-gas system (Shao et al., 2002).

Application of drag reducing agents in a multiphase oil-water-gas system

A multi-phase oil-water-gas system was simulated by storing 700 liters of crude oil and 1000 liters of water in a 2.5 m^3 tank made of carbon steel. The crude oil of lower density was pumped from the upper part of the tank while the water was drawn from the bottom using a 6 horse power (HP) external helical gear pump. The flow rate of the crude was controlled by controlling the quantity of oil recycled back to the tank. The water was pumped using a 3 HP air operated double diaphragm centrifugal pump with the water flow rate controlled downstream the pump using a control valve. The oil and water flow, respectively into 9.0 cm polyvinylchloride (PVC) pipelines where liquid flow rates were measured using orifice plates manufactured to give a range of liquid velocities between 0.05 to 1.5 m/s. Pressure transducers calibrated with U-tube manometers were also attached to the orifice plates. The oil-water mixture combined in a tee section passes into a 1m^3 mixing tank made of carbon steel where carbon IV oxide stored in a 30-ton liquid receiver was introduced into the system at a constant pressure of 30 barg with the flow rate of

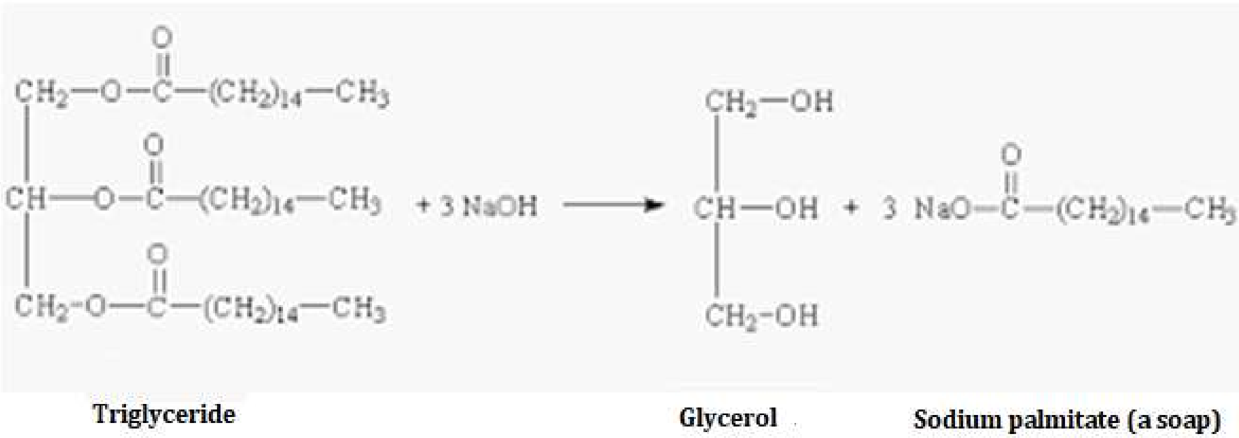

Fig. 1: Saponification reaction to form a stabilizing agent (soap) for DRA

the gas regulated using a positive displacement gas flow meter and then fed into the bottom of the mixing tank simulating the flow from an oil well. The multiphase oil-water-gas mixture flows into a 10.0 cm PVC pipeline where pressure gradient, flow distribution, velocity and frequency are monitored and recorded as control. The DRA solution with weight % concentrations 25, 50 and 75 and 100 continuously flow for 24 hours per day using a 1 bar pressure to force the DRA through a 0.755 cm diameter vinyl tubing downstream the pump to avoid high shear conditions and slightly into the mixing tank with the DRA entering the pipeline near the pipe wall. The pressure gradient and efficiency factors were measured for each concentration of DRA as shown in following section (Abubakar et al., 2014).

$$\text{Drag reduction (\%)} = \frac{\Delta P_{\text{without DRA}} - \Delta P_{\text{with DRA}}}{\Delta P_{\text{without DRA}}} \times 100 \quad (1)$$

Where, $\Delta P_{\text{without DRA}}$ = Pressure gradient without DRA and $\Delta P_{\text{with DRA}}$ = Pressure gradient with DRA.

$$E_{DRA} = \frac{\text{Drag reduction (\%)}}{C_{DRA}} \quad (2)$$

Where, E_{DRA}= Efficiency factor and C_{DRA}=DRA Concentration

$$V_{DRA} = \frac{C_{DRA} \times V_{total}}{1 \times 10^6} \quad (3)$$

Where, VDRA = Volume of DRA to be added, CDRA = DRA Concentration and V_{total} = Total liquid volume of the system

$$Re = \frac{\rho\, D\, \mu_{ave}}{\mu} \quad (4)$$

$$f = \frac{D\, \Delta P}{\rho \mu_{ave}^2 2L} \quad (5)$$

Where, ρ = Liquid Density, μ = Liquid Velocity, D = Inside diameter of pipeline, μ_{ave} = Average liquid Velocity, L = Length of pipe through which pressure gradient was measure, f = fanning factor and Re = Reynolds number.

RESULTS AND DISCUSSION

Polymers obtained from suitable monomers are major ingredients of drag reducing agents (DRAs), they play important roles in reducing friction and drag along expedition lines. Crude oil exports which are achieved through discharge pumps of various capacities are necessary to reduce friction along export lines and this results in high level of global demand. The use of certain polymeric materials to reduce pumping requirements and in turn reduce frictional drag is an essential requirement in most oil field operations (Xi and Graham, 2012). Although the exact reaction between the DRA and the crude which in turn results in drag reduction is still subject to series of research however it is believed that the drag or frictional reduction is caused by the elasticity of the polymer chains. The stretching of the randomly coiled polymer chain increases its viscosity thereby reducing the frictional force along the walls of the expedition lines which in turn increases the dimensions of the wall thereby resulting in the observed drag reduction (Wang et al., 2017). The polymer used as DRA must be soluble in the hydrocarbon fluid and the energy extracted from the countercurrents or swirl wind between the walls of the expedition line is as a result of the stretching of the molecules of the polymer around the vortices. This assertion

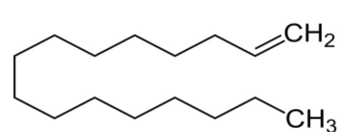

Fig. 2: α-β unsaturated hexadecene

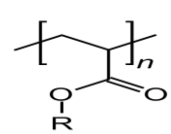

Fig. 3: Pour point modifier for DRA (Polyacrylate)

Table 1: Composition of drag reducing agent

α-olefin polymer (wt%)	Vegetable oil (wt%)	Stabilizing agent (wt%)	Pour point modifier (wt%)	Total concentration (wt%)	V_{DRA} (mL)
8.0	12.0	3.0	2.0	25.0	42.5
15.0	25.0	6.0	4.0	50.0	85.0
20.0	40.0	8.0	7.0	75.0	127.5
25.0	50.0	15.0	10.0	100.0	170.0

is confirmed by the transfer of power from the polymeric substance to the flowing fluid. The structural changes in turbulence and disarrangement arising from the directional difference in viscous effect on the flowing fluid by the stretched polymer results in drag reduction. The polymer of α-β unsaturated hexadecene was used for this study (Hidema et al., 2018; Ralf et al., 2004).

Vegetable oils are important ingredients of drag reducing agents, they serve as carriers of DRA thereby giving them the desired flow characteristics. Vegetable oils are critical in DRA to prevent separation during flow, adequate permeability within the internal bonds of the fluid for optimal results and to prevent backpressure arising from narrow and long injection pipelines. Vegetable oils such as castor oil used in this study is inert to the active compound of the DRA, environmentally friendly and user safe (Nesyn et al., 2018).

Fatty acid salt obtained from saponification reaction between a suitable alkaline such as sodium hydroxide and fatty acid is used as a stabilizing agent for DRA. Stabilizing agent can also comprise of other constituents such as wetting and dispersing agents, surfactants, polymeric dispersants and ant-agglomerating agents (Kwiatkowski et al., 2018). The alpha-beta unsaturated hexadecene polymer can form a stabilized dispersion using the stabilizing agent by mechanical grinding. Sodium palmitate obtained from the reaction between triglyceride and sodium hydroxide was used as the stabilizing agent for the DRA. The stabilizing agent gives the DRA an adequate viscosity suitable for the crude oil mass fluidification and drag reduction demands (Wang et al., 2017). The stabilizing agent has anti degradation characteristics which it introduces into the DRA. A mixture of DRA and stabilizing agents or surfactants gives the DRA a good drag reduction effect at higher Reynolds numbers, high shear resistance and a lower critical micelle concentration which is an important property of surfactants (Choi and Acosta, 2018). Polymeric drag reducers like the one considered in this study have inherent limitations such as irreversible mechanical degradation under shear however to achieve a suitable drag reduction effect, the concentration of the stabilizing agent must be up to the critical micelle concentration (CMC). The CMC is the concentration of the surfactant (in a bulk phase) above which aggregates of surfactant molecules called micelles begin to form (Kwiatkowski et al., 2018; Biggs et al., 1992).

Pour point of a fluid composition is the temperature at which a hydrocarbon fraction begins to flow. The pour point of the composition could be determined visually by estimating whether the composition is flowing in certain temperature (Nesyn et al., 2018). Pour point modifiers in most cases are used synonymously with phrases such as pour point depressants or viscosity index improvers. Pour point modifiers reduce the pour point and improves the cold flow properties of DRAs (Guilherme et al., 2019). Pour point modifiers are very critical in crude oil transportation and are important ingredients in DRA. Pour point modifiers acting as pour point depressants in DRA such as the one used in this study has the ability of reducing the solidifying points of wax-bearing crude such that the crude oil is at the flow state at the transportation temperature and the flow resistance in the expedition line is reduced remarkably (Liberatore et al., 2004).

The total concentration of the DRA was determined by the individual concentrations of the constituents that makes up the DRA as shown in Table 1. The % drag reduction which is a reflection of the drag reducing capacity of the DRA was determined using equation 1. Pressure gradient can be defined as the difference in pressure with horizontal distance. Pressure gradient is high when there is a rapid change in pressure within a short distance and mild when pressure only changes within a long distance (Wang et al., 2017). The % drag reduction is calculated from the pressure gradient obtained when the transported fluid flows without a DRA and when it flows with a DRA as shown in equation 1. The efficiency factor E_{DRA} which indicates the ability of the DRA to overcome the frictional force of the flowing fluid along the pipeline is calculated for each DRA concentration as shown in equation 2. The volume equivalent of the DRA with respect to the concentration is calculated using equation 3. From Table 2 it can be deduced that the concentration of the DRA is inversely proportional to the pressure gradient and directly proportional to the % DRA and efficiency factor respectively (Shao et al., 2002).

The slug and flow characteristics of the transported fluid in a multiphase oil-water-gas system indicated by the Reynolds number and fanning factor is shown in Table 3. The Reynolds number and fanning factor are calculated using the liquid density, velocity as well as other parameters such as the internal diameter of the pipe (0.755cm) and length of the pipe (10.0 cm) as shown in the Blasius equation in equations 4 and 5 respectively (Abubakar et al., 2014). The Reynold's number is a dimensionless quantity used in determining the flow pattern of a fluid whether laminar or turbulent. Stokes or creeping flow are associated to very small Reynolds

Table 2: Pressure gradient and efficiency factor of drag reducing agent

C_{DRA} (wt %)	P_{dep} (Bar)	$P_{arr\ (without\ DRA)}$ (Bar)	$P_{arr\ (with\ DRA)}$ (Bar)	$\Delta P_{without\ DRA}$ (Bar)	$\Delta P_{with\ DRA}$ (Bar)	% DRA	E_{DRA}
25.00	12.77	3.95	5.20	8.82	7.57	14.17	0.57
50.00	12.71	3.95	7.00	8.76	5.71	34.82	0.70
75.00	12.78	3.64	8.80	9.14	3.98	56.46	0.75
100.00	12.77	3.52	12.00	9.25	0.77	91.68	0.92

Table 3: Flow and slug characteristics of fluid in a multiphase oil-water-gas system

CDRA (%)	Liquid density (g/cm^3)	Liquid velocity (m/s)	Re	$\Delta P_{with\ DRA}$ (Bar)	f
25.000	0.8778	1.5000	0.3314	7.5700	0.5788
50.000	0.8892	0.8000	0.6294	5.7100	0.4311
75.000	0.9154	0.6000	0.8639	3.9800	0.3000
100.000	0.9331	0.1000	5.2837	0.7700	0.0580

number much less than 1 while smooth and laminar flows are associated to much higher Reynolds number greater than 1. The higher the drag reducing ability of a DRA the higher its Reynold's number as shown in Table 1 (Xi and Graham, 2012).

The fanning factor which is also known as the fanning friction factor is defined as the ratio between the shear stress and the kinetic energy flow density, it is a very important parameter in continuum mechanics and it is inversely proportional to the Reynold's number however the relationship of both parameters are quite complex in turbulent flows The shear stress at the walls of the export line can be related to the pressure loss from the fluid departure to arrival by multiplying the wall shear stress by the wall area (Liberatore et al., 2004).

CONCLUSION

The operation of export pumps in the discharge of crude oil and associated fluids such as gas and water along expedition lines has resulted in a great deal of energy demand globally. Properly formulated Drag reducing agent (DRA) is very important in overcoming the frictional disturbance along the export line thereby ensuring a laminar flow which is essential to boost production. The primary constituents of the DRA ranging from α-β unsaturated hexadecene, vegetable oil, sodium palmitate as stabilizing agent and pour point modifier in the appropriate concentrations were very essential in the overall function of the DRA. In a simulated multiphase oil-water gas system, different concentrations of DRA reduced the pressure gradient along the export line travelled by the transported fluid. The higher the concentration of the DRA, the lower the pressure gradient and the higher the drag reducing ability of the DRA, which is reflected in the %DRA and efficiency factor (E_{DRA}). The flow distribution and slug characteristics of the transported fluid after treatment with different concentrations of DRA were quantified using the Reynolds number and fanning friction factor. The Reynolds number is a reflection of the speed and smoothness of the flow while the fanning friction factor is a reflection of the frictional disturbance inherent along the export line. The Reynolds number and fanning friction factor are inversely proportional, the higher the Reynolds number, the smoother and more laminar the fluid flow along the line and the lower the fanning friction factor.

DECLARATION OF COMPETING INTEREST

The authors declare no competing financial interest.

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