Optimization of Application Conditions of Drag Reduction Agent in Product Oil Pipelines

Xiaodong Dai,* Cuiwei Liu, Jishi Zhao, Lei Li, Shuming Yin, and Huanrong Liu

ABSTRACT: Drag reduction performance was studied with a rotating disk instrument in the laboratory, and experiments show that there is an initial rapid growth stage and stability stage for drag reduction ratio change. The higher the rotational speed, the larger the initial drag reduction ratio is; the larger the concentration, the shorter the drag reduction stabilization time is. Under high concentration and high speed, the drag reduction onset time is short. Because of the shear degradation, the Reynolds number should be taken into account during use. Through a comparison of diesel properties after adding agents with national standard, it is confirmed that drag reduction agents could be used in this pipeline.

1. INTRODUCTION

More than 24,000 km of product oil pipelines have been constructed and used in China by 2018. Therefore, it is necessary to improve transport efficiency and satisfy logistics demands. The drag reduction technology of pipelines mainly includes rib drag reduction, viscous drag reduction, bionic drag reduction, and wall vibration drag reduction, among which the drag reducer technology belongs to viscous drag reduction. Compared with other technologies, the drag reducer technology does not need to improve the pipeline, and its cost is lower; thus, it is widely used in oil pipeline transportation. The drag reduction agent (DRA) could be polymers with high molecular weight or a surfactant which could suppress the turbulence in the pipelines. The drag force decreases because of the addition of DRA, and it allows oil to be pumped under lower pressures. Furthermore, because the whole pipeline would be operated under lower pressure compared with the pipeline with no DRA addition, the whole pipe system is safer.

Many results have been obtained for the degradation of DRAs with measurements in a rotating disk apparatus. Kim studied polystyrene with a high molecular weight in a rotating disk apparatus. In several concentrations, the drag reduction was found to be time dependent in different solvents. In good solvents for DRAs, the drag reduction is larger and can maintain for a relatively long time than that of poor solvents. This conclusion is also supported by Zakin and Hunston. Choi and Lim studied the degradation of deoxyribonucleic acid (DNA) as a drag-reducing agent. They found that the degradation stopped at a certain level and the effectiveness of DNA in the drag reduction could maintain for a longer time than polyacrylamide. This advantage may be credited to the helical structure and monodisperse-molecular weight of DNA.

In this study, a laboratory investigation of the DRA performance has been conducted, and the influence factors include time, concentration, Reynolds number, and temperature. Those results will provide the theoretical reference for the optimization of DRA application; the basic working conditions of the pipeline are as follows: the diameter is 300 mm, length is 150 km long, conveying capacity is $5 \times 10^6$ t/a, and maximum pressure is 6.0 MPa.

2. EXPERIMENT

2.1. Materials. The properties of DRA used (in slurry form, containing 30% poly-$\alpha$-olefin, Weipu Pipeline Technology Corporation, China) are shown in Table 1. Diesel #0 with Chinese V standard used in the experiment is supplied by the pipeline operator, and its properties are listed in Table 2.
and 3 mm, respectively. The type of torque sensor with a measurement range of 0−5 N·m and precision of 0.0001 N·m is YH502. The type of speed regulating motor is 90ST-M02430, and its speed range is 0−3000 rpm and rated torque is 2.4 N·m. The type of water bath is HH-501 with an output power of 1 kW and temperature accuracy of ±0.5 °C. The experimental data are collected by software. The type of ultrasonic generator is PS30 with an output power of 180 W and frequency of 40 kHz, and its heating output power is 200 W and temperature range is 20−80 °C.

2.3. Drag Reduction Experiment. According to the Chinese Standard of Laboratory testing method for the DRA performance (SY/T6578-2009), it requires to premix slurry DRA to a concentration of 1 g/L with diesel or other nonpolar solvents before the experiments. The diluted DRA with a certain amount was added into the rotating disk device and distributed evenly by nitrogen aeration to guarantee that the measured drag reduction effect was under a stable condition.

The rotational Reynolds number \( N_{Re} \) is calculated by eq 1.15

\[
N_{Re} = \frac{\rho r^2 \omega}{\mu}
\]

where \( \rho \) and \( \mu \) are liquid density and viscosity; \( \omega \) is the angular velocity; and \( r \) is the radius of the disk.

Diesel solution (1000 mL) was added into the stainless steel container and kept in a water bath at 25 °C for 4 h. Then, DRA with different concentrations was added into the container. The variation of speed and torque were recorded automatically. The force \( F \) can be calculated by eq 2.16

\[
F = \eta \frac{dv(r)}{dr} S = \eta \frac{d\omega r}{dr} S = \eta \omega S
\]

where \( S \) is the area vertical to the rotating direction and \( v(r) \) is the linear velocity at \( r \). The torque \( (T) \) can be calculated by eq 3.17

\[
T = r \times F = \eta \omega S r
\]

Finally, the drag reduction ratio was calculated according to eq 4.18

\[
\text{DR} \% = \frac{T_s - T_p}{T_s}
\]

where \( T_s \) and \( T_p \) are the torques of diesel and DRA/diesel solution, respectively, at 25 °C.

3. RESULTS AND DISCUSSION

The experiments were conducted based on the properties of fluid and operating parameters in combination with actual operating conditions of pipelines, such as DRA, time, \( N_{Re} \), and temperature.

3.1. Blank Test without DRA Addition. 3.1.1. Viscosity−Temperature Curve of Diesel. The relationship between the viscosity and temperature of the diesel sample was measured by the rotational viscometer (Figure 2). It can be found that the diesel viscosity declines almost linearly with the temperature. Therefore, higher turbulence occurs during diesel transportation under the same operating conditions.

3.2. Relationship between Time and Drag Reduction. At 25 °C, the relationship between the drag reduction effect

| sample | density (20 °C), kg/m³ | freezing point, °C | flash point, °C | kinematic viscosity (20 °C), mm²/s | 50% | 90% | 95% |
|--------|------------------------|---------------------|-----------------|-----------------------------------|-----|-----|-----|
| Diesel | 825.4                  | −2                  | 76              | 4.332                             | 278.4 | 334.7 | 347.6 |
calculated by eq 2 and the operating parameters is shown in Figure 4. Regardless of the concentrations and the rotating speeds, the drag force reduces rapidly with the addition DRA before the first 15 min. Because poly-α-olefin molecules stretch fastly with high shear force at high rotating speed, the drag force reduction value is larger with the higher rotating speed at time 0. It will take a longer time to achieve a stable drag force reduction with low rotating speed. Therefore, the high shear force based on eq 1 can help to reach a stable drag force reduction or DRA stretching.19

Figure 4a shows under the condition of 10 mg/L DRA, the stable time of drag reduction percent (DR %) is about 80 min at 800 rpm, and it decreases to 30 min at 1300 rpm. Figure 4b shows that a stable time of the DR ratio is 20–60 min with 20 mg/L DRA. Figure 4c shows that DR % can stabilize at 15 min under different speeds with 40 mg/L addition of DRA. Therefore, the high DRA concentration will also shorten the stabilization time besides the high turbulence with shear force. The high DRA concentration adds to the viscosity of the diesel, and the stretching rate of the DRA increases with the turbulence and the shear force.20

3.3. Relationship between \( N_{Re} \) and Drag Reduction. Because poly-α-olefin can degrade under intensive shear circumstances for a long period, the turbulence \( (N_{Re}) \) has an influence on the DRA performance during diesel transportation.21 The relationship between \( N_{Re} \) and DR % was studied with the DRA addition of 10, 20, and 40 mg/L at 30 °C. Figure 5 shows that DR % increases with \( N_{Re} \) before \( N_{Re} = 309,551 \) and reached the maximum value at \( N_{Re} = 309,551 \). Then, DR % drops with \( N_{Re} \). The shear force enhances the DRA stretching when \( N_{Re} \) is less than 309,551, and the drag force reduction is observed. However, the molecular structure of the DRA could be physically damaged when the shear force is too large (\( N_{Re} \leq 309,551 \)), such as losing the branch chains, and this will lead to a decrease in molecular weight and performance degradation of DRA. It is also interesting that the damage degree of molecular structure is different at the same turbulence with different DRA concentrations. The high DRA addition leads to the increase of viscosity, and the rotating speed should be high at the same \( N_{Re} \) with low DRA concentration based on eq 1. Therefore, low DRA concentration can handle high rotating speed without degradation.

In the pipeline transportation, the high shear force occurs at regulating valves, bends, and pipe tees. Thus, if there are many

Figure 3. Mean torque of diesel at a different rotating speed at 25 °C.

Figure 4. Effect of \( N_{Re} \) to DR % at 10 (a), 20 (b), and 40 mg/L (c).

Figure 5. DR % at different turbulences.
shearing force-generating spots along the pipeline, more DRA replenishment is required during oil transport.

3.4. Relationship between Temperature and Drag Reduction. The oil temperature varies during transportation, and it is necessary to study the temperature effect on drag reduction. Samples with DRA concentrations of 10, 20, and 40 mg/L were tested between 20 and 50 °C at 1000 rpm, and the DR % results under different concentrations are shown in Figure 6. DR % increases linearly with temperature. High temperature reduces the viscosity of the fluid normally, and it tends to lead to low turbulence ($N_{Re}$). However, the high temperature also enhances the stretch of the polymer at low temperatures; thus, it enhances the drag reduction effect.22 The high temperature facilitates the increase of the drag reduction effect; thus, the molecular stretching effect suppresses the viscosity reduction effect with increasing temperature.

3.5. Influence of DRA on Properties of Diesel. Because the DRA is composed of poly-$\alpha$-olefin and an organic solvent, it is necessary to investigate its influence on product oil properties, although the DRA concentration in the diesel is low. The measured properties of diesel are shown in Table 3 with 40 mg/L DRA with addition prior to and post the shearing forced degradation (2700 rpm for 60 min). It could be seen that both diesel samples still meet the national standard, as shown in Table 1, which indicated that the DRA has no significant influence on diesel quality.

4. CONCLUSIONS

A laboratory experiment has been conducted to investigate the factors that are able to affect the performance of DRA in diesel transportation. The influence factors include time, concentration, Reynolds number, and temperature. The results show that flow resistance can be effectively reduced by adding DRA in diesel, and the stabilization time of DRA is directly related to the shear force affected by the concentration and the disk rotating speed. DR % can be improved by increasing turbulence $N_{Re}$. The high temperature will enhance the stretching of poly-$\alpha$-olefin and reduce the drag force of the diesel during transportation, and adding DRA has no obvious influences on diesel properties. The results will provide the theoretical reference for the optimization of DRA applications.

Table 3. Diesel Quality Comparison after Adding DRA and Shear Degradation

| sample                        | density at 20 °C, kg/m$^3$ | freezing point, °C | flash point, °C | kinematic viscosity at 20 °C, mm$^2$/s | boiling range °C |
|-------------------------------|-----------------------------|---------------------|----------------|----------------------------------------|-----------------|
|                               |                             |                     |                |                                        |                 |
| diesel of adding DRA (no shear) | 825.6                       | -3                  | 76             | 4.371                                  | 278.0           |
| diesel of adding DRA (shear degradation) | 825.6                       | -3                  | 77             | 4.352                                  | 278.0           |

Notes

The authors declare no competing financial interest.

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