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Effect of Lubricants on the Lubricity of an Intervention Base Oil

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ABSTRACT

During well intervention operations, the production tubing wall could be worn out due to mechanical interaction with coil tubing. Wear damage is a critical issue in the bend section where the contact force is higher. One of the possible solutions to reduce friction and wear damage is by increasing the lubricity of the intervention and the drilling fluid as well. The improved lubricity also minimizes the torque and drag that allows for reaching longer offset.
This paper presents the experimental studies of the impact of six lubricants on industry intervention fluid. Results showed that the lubricants enhance the lubricity of the base oil. The optimized concentration of the lubricant reduced the coefficient of friction by 42-72 %.

INTRODUCTION

During drilling, casing running, and coil tubing intervention operation, the movement of the strings relative to the wellbore/casing/tubing encounters a resistance frictional force. The higher friction results in higher torque and drag and causes higher tubing/casing wear damage. The overall impacts may reduce the target depth reach and result in tubular integrity issues as well.

Casing wear is a critical issue in oil well operation.[1]. In Gullfaks A-42, the measured casing wear indicated that about 35% of the wall thickness had been removed due to the drill string's tool joint and casing mechanical interactions.[2] In one of the North Sea wells, the production tubing's wear measurement showed that about 47% of the wall thickness of the tubing had been reduced in the bend section.[3] Out of the seventy-two production and injection wells, the well integrity survey recorded about 39% of the integrity failure was associated with production tubing and 11% with casing.[4] Finite element modeling results showed that local wear damage degrades tubular burst/collapse rate significantly.[5]

Rheology and Tribology are among other fields of study that determine fluid viscosity and lubricity behaviors. Tribology studies surfaces of interacting moving objects relative to one other that deal with friction, wear, and lubrication.[6-7] The lubrication of the drilling/ intervention fluids controls the resistance of the relative motion/sliding of the string (i.e., friction) and the degree of wear (i.e., loss of the materials). The lubricant film layer separates the two sliding surfaces so that it will reduce friction and wear. However, lubricity, which has properties such as strong film, long-term durability, and resistance to thermal/mechanical degradation, will ensure its effectivity concerning friction and wear reduction of the string. Therefore, Tribology is also one aspect of the basic design when formulating drilling fluids regarding rheological properties.

A company in the North Sea uses base oil for intervention operations. However, the base fluid alone is insufficient for friction and wear reduction. Therefore, this paper will investigate the impact of a total of six lubricants on the lubricity of intervention fluids through laboratory lubricity measurement.

MATERIALS AND METHODS

This section presents the materials and the characterization methods.

Materials

A total of six lubricants and intervention base- oil have been received from the local service companies (Stavanger, Norway).

Characterization and Analyses Methods

Anton Paar Rheometer

The viscosity behavior of the best-optimized lubricant blended with the base fluid has been measured by the Anton Paar rheometer (MCR 302)(Anton Parr GmbH, GRAZ, AUSTRIA).

CSM Tribometer

CSM Tribometer (CSM Instruments, Needham, Massachusetts, USA) was used to measure the lubricity of the fluids. **Fig. 1** shows the schematic friction testing conducted by applying a 5 N load on a steel ball-plate interface. The cup was filled with lubricity test fluid, which is lubricant blended base oil. The 13cr steel ball has a diameter of 6 mm, and the cup rotates at a speed of 3 cm/s for about 10 m. All the measurements were conducted at 20 ^{0}C. The ball-plate interaction causes surface damage, as shown in the **Fig. 2**.

During testing, both the cup surface and the ball were monitored, and changes were made to achieve a representative measurement. Due to the variation of the surface damages, several repeat tests were performed for statistical purposes. The average values of test results were reported.

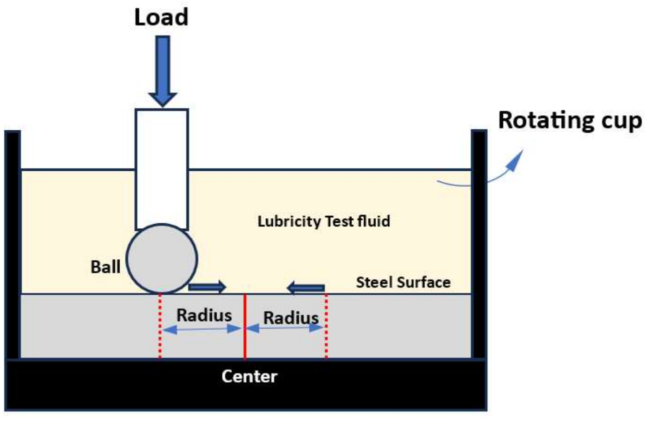

FIGURE 1: Schematic friction testing

FIGURE 2: Photograph picture damaged ball and surface

Previous studies on the lubricity of oil and water-based oil indicated the impact of temperature on lubricity.[8] However, due to the intervention fluid's volatile nature, the temperature's effect on the lubricant /based oil blended fluids was not measured. This was due to the absence of ventilation in the laboratory, which could mitigate the risk of personal health issues.

Lubricant in base oil formulation

Table 1 shows the concentration of the lubricant in wt.% and grams. The weight percent is the mass ratio of lubricant to base oil. The first sample is lubricant-free base oil, which is used as a control. The lubricant effect will be analyzed by comparing it with the reference/base oil.

TABLE 1: Lubricant blended base oil test fluid formulation.

Sample #	Base oil g	Lubricant wt.% (g)
1	130	0 (Control)
2	130	0.5 % (0.65 g)
	130	1.0 % (1.30 g)
4	130	2.0 % (1.95 g)
	130	2.5 % (2.65 g)
6	130	3.0 % (3.90 g)
	130	10 % (13.00 g)

Five lubricants obtained from service companies were tested and labeled as lubricants A, B, C, D, and E for confidential reasons. In addition, the lubricant labeled P is called Prolong Olje+.[9] **Fig. 3** shows the lubricants before mixing with the base oil. As shown, the viscosity and textures are quite different. The base-oil-free lubricants were not characterized.

FIGURE 3: Photograph picture of the lubricant samples A, B, C, D, E, and P(Prolong olje+)

Before mixing the lubricant with the base oil, the lubricants were shaken well while in the fluid holder. In the measured 130g base oil, the desired lubricants were added according to Table 1. The lubricants are heavier and settle out at the bottom of the base oil. To have a good mixture, we first used a magnetic stirrer for about 10 minutes, and then the mixed system was also sonicated with ultrasonication for 2 minutes at lower energy. This is done to make sure that the system is mixed well and that the ultrasonicate will not cause any structural damage to the fluid system. However, after mixing, some of the lubricants exhibited different sagging phenomena, as shown in **Fig. 4-9**. In the pictures, the concentrations of lubricants in the base oil are varied in the range of 0.5 wt.% to 10 wt.%.

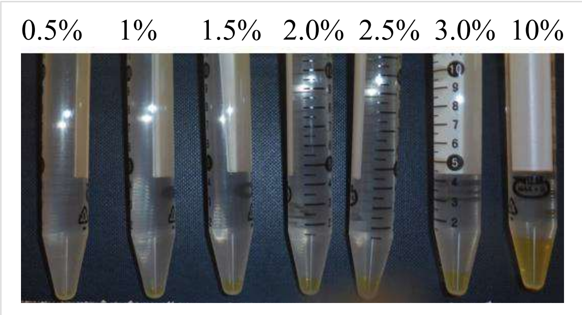

FIGURE 4: Lubricant A blended base oil.

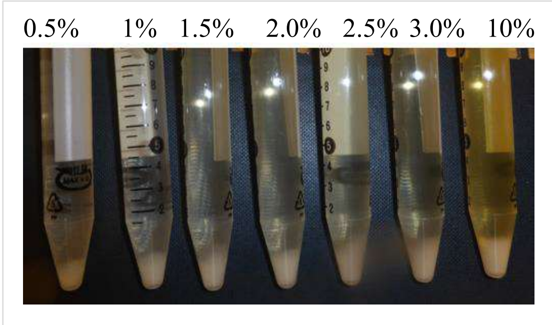

FIGURE 5: Lubricant B blended base oil.

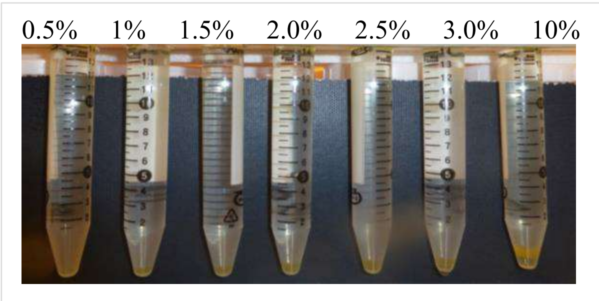

FIGURE 6: Lubricant C blended base oil.

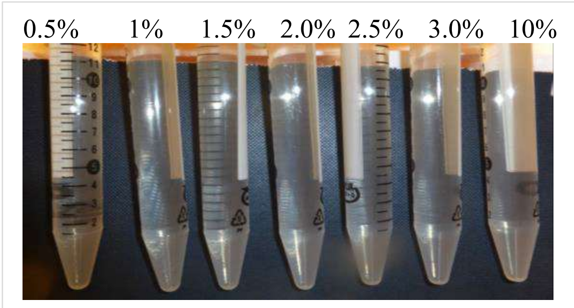

FIGURE 7: Lubricant D blended base oil.

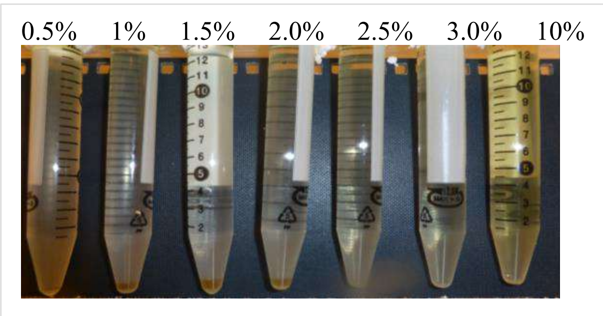

FIGURE 8: Lubricant E blended base oil.

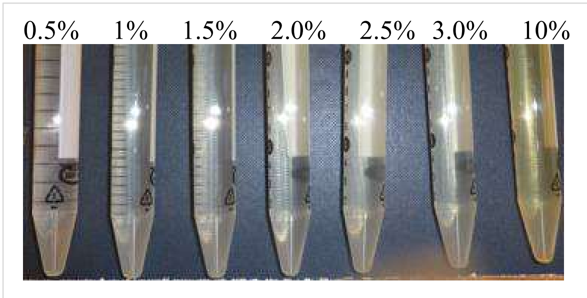

FIGURE 9: Lubricant Prolong Olje+ blended base oil.

Depending on the solubility and the nature of the lubricants, some of the solutions show a clear lubricant settling (A, B, C, E), and some of them are colorless (D and Prolong Olje+). Unlike others, lubricant B showed more particle-like sagging. This could be due to the chemical interaction of the lubricant with the base oil.

RESULTS AND DISCUSSION

Effect of lubricant on the base fluid

Several tests have been performed on each sample, and the trend lines are nearly similar. However, since the magnitude and trend of the dataset vary due to the condition of the ball – and surface, all the datasets were summed, and their mean values were reported. **Fig. 10** and **Fig. 11** show the mean measured coefficient of friction (COF) of the bases oil and lubricants blended based oil, respectively.

Result analysis showed that most of the base oil dataset exhibited an increasing trend, which is associated with surface damage due to the lack of a thin film layer, or the film layer of the base oil is not strong enough to slide the ball without scratching the plate.

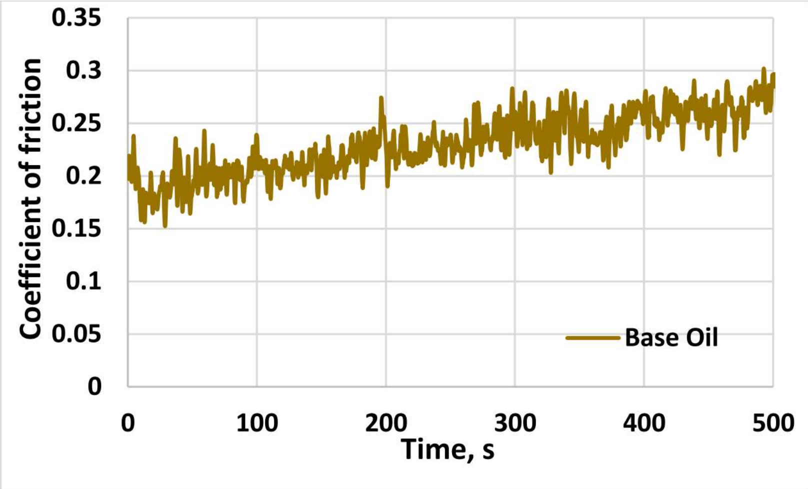

FIGURE 10: Base-oil coefficient of friction measurement vs time

On the other hand, **Fig. 11** shows the lubricant-based solutions recording relatively stable and reduced coefficient frictions. This could be due to the performance of film generated from the lubricant.

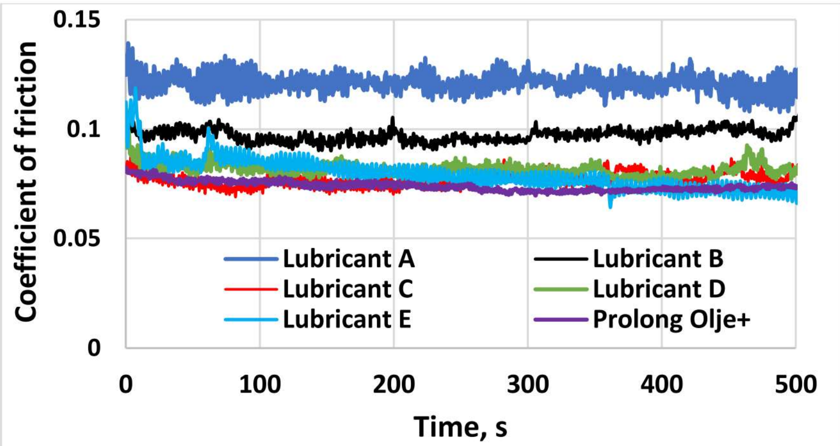

FIGURE 11: Effect of lubricants on the base-oil coefficient of friction measurement vs time.

Further, **Figs. 12-17** shows the measured mean coefficient of friction of several tests over the test 10 min duration along with the computed percentile reduction compared with the base oil. As shown in the figures, all the lubricants improved the lubricity of the base oil. However, the effects are non-linear and display a 'U' shape as also observed in reference.[15] When the concentration of the lubricants increases, the lubricity increases until a specific concentration, and then the impact will be degraded by increasing lubricant. The lubricant's performance in the base oil varies. The possible factors, among others, could be associated with the lubricant film layer, its strength for the shear load, the lubricant adhesion with the substrate, and the solubility with the base oil.

The optimum lubricant concentrations of lubricants A, B, C, D, E, and P (Prolong olje+) were 1.0wt. %, 2.0 wt.%, 1.0wt%, 2.5wt%, 1.5wt%, and 3.0wt.%, respectively. The percentile reduction of the base oil coefficient of friction for these optimum concentrations was -70.8%, -42.7%, -60.4%, -72.3%, -66.4%, and -66.2%. Please note that changing the temperature may achieve different results.

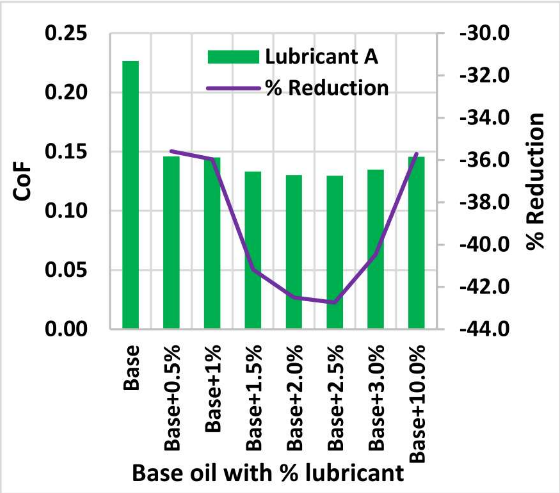

FIGURE 12: Effect of Lubricant A on base oil.

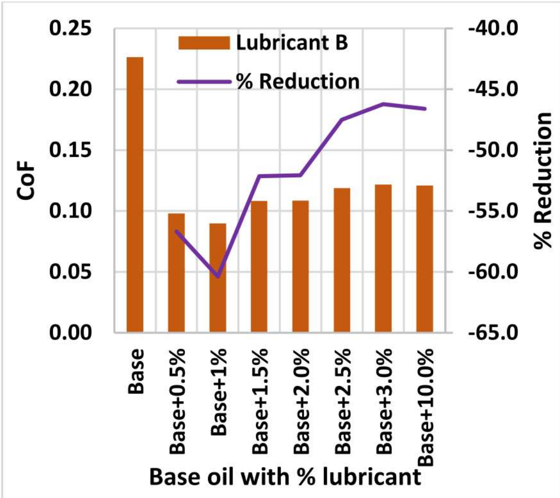

FIGURE 13: Effect of Lubricant B on base oil.

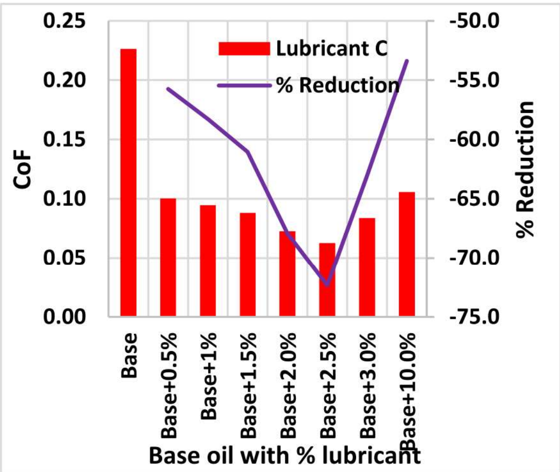

FIGURE 14: Effect of Lubricant C on base oil.

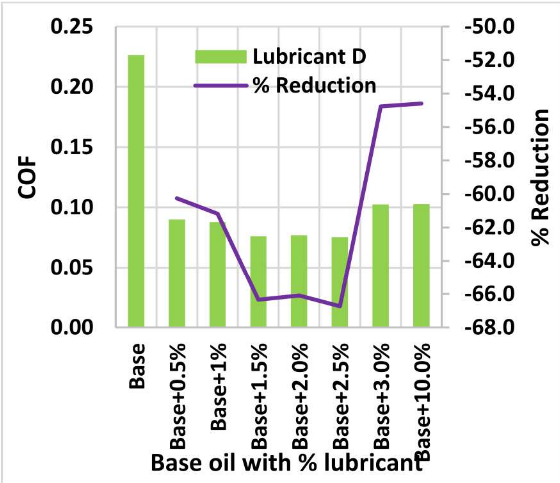

FIGURE 15: Impact of Lubricant D on base oil.

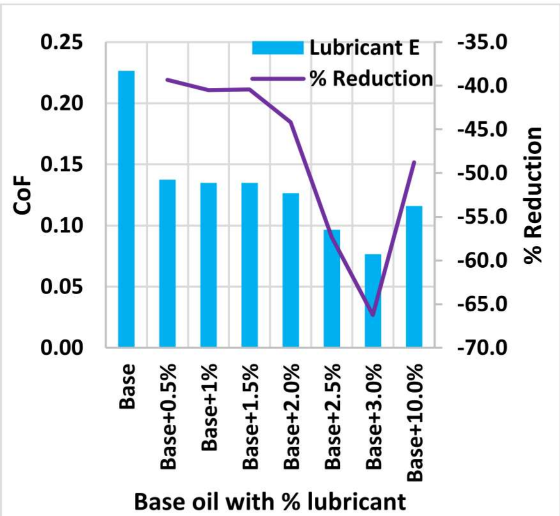

FIGURE 16: Impact of Lubricant E on base oil.

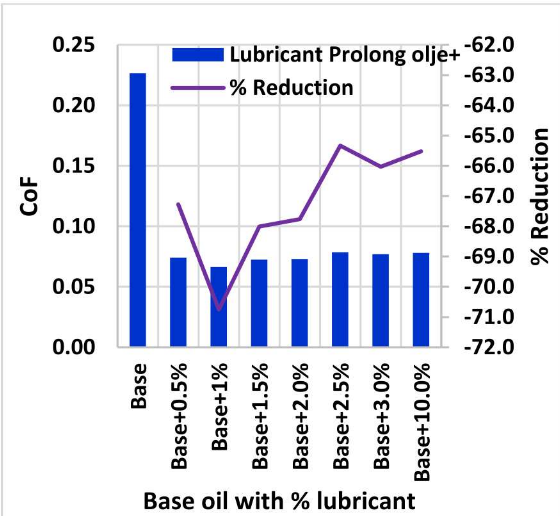

FIGURE 17: Impact of Prolong Olje+ on base oil.

Lubricity of the lubricant effect on the base fluid

The viscosity of the best-optimized lubricant blended base oil solution was further measured with an Anton Paar rheometer. **Fig. 18** shows the measurements. As shown, all fluids behave like Newtonian fluids. The slope of the stress-shear rate curve represents the viscosity of the solutions. The results are displayed in **Fig. 19**. As shown, except for lubricant D, all others enhanced the viscosity of the based oil, but the impact is insignificant. The results indirectly indicate that the viscosity of the solution did not play a role in lubricity for this particular base oil.

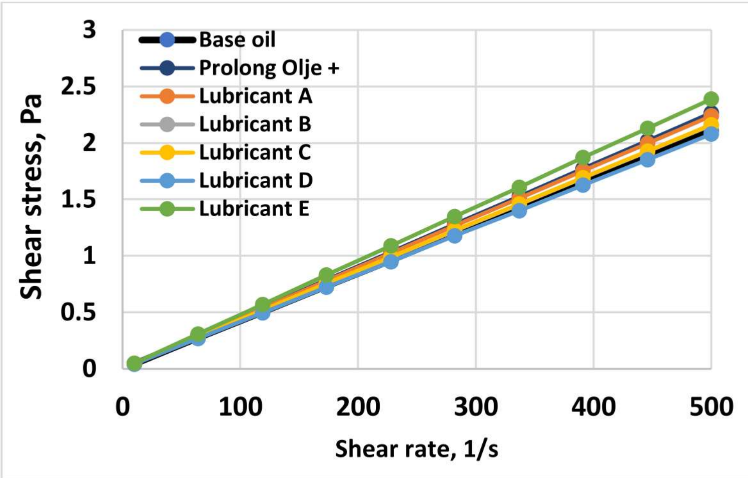

FIGURE 18: Shear stress-shear rate measurement of the base -and lubricant-blended base fluids.

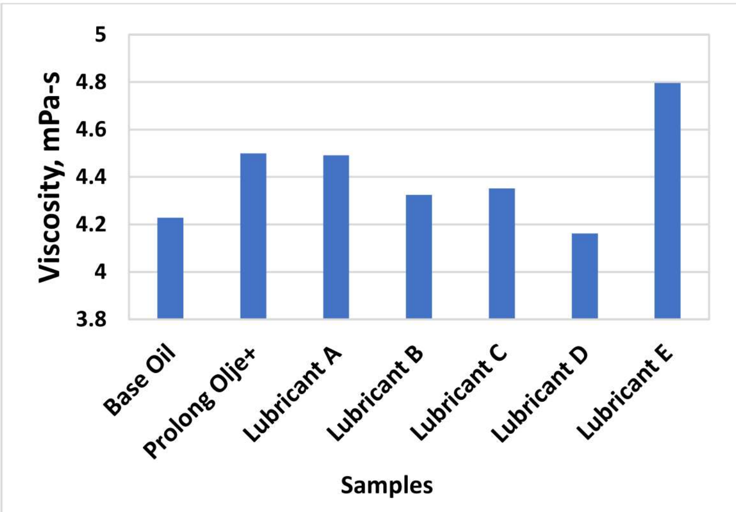

FIGURE 19: Viscosity of the base and lubricant blended base fluids.

MECHANISM AND DISCUSSION

The tribological performance of thin lubricating films is associated with film parameters such as adhesion, cohesion, interface formation, nucleation, microstructural growth, critical film thickness and substrate finish, and temperature.[10] Effective lubrication is therefore achieved through the desirable film structures and thicknesses.[11] The lubricity performance mechanism of nanoparticle systems is categorized as (1) rolling effect, (2) mending effect, (3) polishing effect, and (4) protective film formation effects.[12-14] Since the lubricant blended fluid system is free of nanoparticles, the rolling and polishing surface will not describe the lubricity mechanisms.

The friction coefficient test results showed that the lubricant effect in the base fluid varies with concentration and the type of lubricant. By visual observation, the solubility and sagging description of the lubricants blended with the base oil vary as shown in **Fig. 4-9**. The following presents the possible tribological performance mechanism based on the visual inspection of the lubricant blended systems and the friction coefficient test results.

The friction test results obtained from the base fluid (**See Fig. 10**) showed that friction coefficient increment during the entire test period. This may indicate that the base fluid's adsorption on the ball-metal forms a weak tribo-film. As a result, the film is not strong enough to resist shear force and hence collapsed. The surface, therefore, continuously scratches and increases the friction. **Fig. 20** illustrates the possible lubricity mechanism of lubricant-free base oil, showing that there is no film on the scratched metal surfaces.

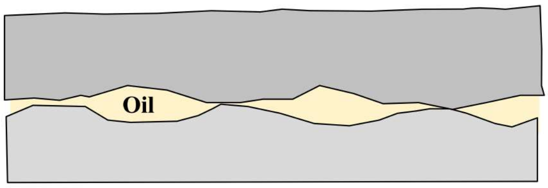

FIGURE 20: Schematic illustration of a film-formation mechanism for base oil.

As shown in **Fig. 4-9**, the lubricant settled out at the bottom and is believed to form a film layer. Since the thickness and the nature of the layer vary, two possible tribofilms are proposed. The reason for the mechanism is that, unlike the base oil, all the lubricants enhanced the lubricity of the base oil either by reducing or maintaining the friction coefficient nearly constant as shown in **Fig. 11**.

Shaking the sample holders of Lubricant B (**See Fig.5**), the sagged lubricant dispersed as small particles in the base oil. Therefore, the film is assumed to contain small particles for this particular lubricant. The particles deposited on a scratched surface and hence have a mending/repair effect in the same way as nanoparticles.[12-14] However, the strength of the film determines how strong the shear/ sliding resistance is. **Fig. 21** is the assumed film formation and lubricant mechanism for lubricant B.

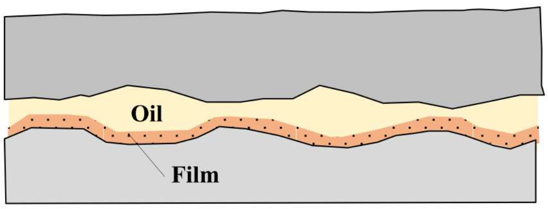

FIGURE 21: Schematic illustration of film-formation mechanism for lubricant-B blended-base oil.

Unlike lubricant B, shaking the sample holders of the rest lubricants (A, C, D, E, and Prolong olje+), none of the settled out lubricants showed particle-like structure, but the lubricant itself dispersed and mixed with the base fluid. For these lubricants, the possible mechanisms for lubricity enhancement could be the formation of a thin film layer that fills the wear damage and allows the sliding of the ball by reducing the shear resistance/sliding resistance. **Fig.22** illustrates the fluid film layer being deposited on a scratched surface.

The lubricant performance presented in this paper is valid for the considered applied load, rotational speed, and temperature. However, increasing the load may destroy the integrity of the lubricating film. Higher temperatures also reduce the film's viscosity, and the film's internal cohesion and surface adhesion may also be weakened. Temperature effects on the water and oil-based drilling fluids have been shown to reduce their lubricity.[8] We must therefore simulate typical operational and downhole conditions to gain more insight into the lubricant's performance.

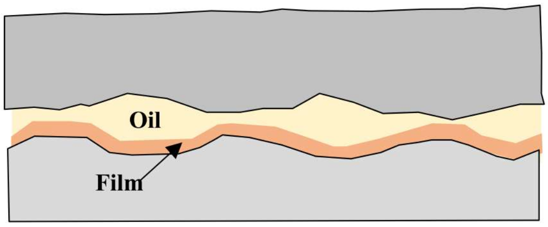

FIGURE 22: Schematic illustrations of a film-formation mechanism for lubricants (A, C, D, E, and Prolong olije+) blended-base oil.

Improving the lubricant property of drilling fluids and interventional fluids, in general, has an impact on prolonging the integrity of the tubular (casing, drill string, tubing, drill bit) by reducing damage due to wear and allowing for drilling a longer offset. However, when designing the lubricant additives, it is also necessary to evaluate their impact on the formation damage. As shown in **Figs. 4-9,** the lubricant in the base fluid formed a particle-like structure, and a sticking-like film settled at the bottom of the sample holder. If these happen in a reservoir, the pore spaces will be damaged and reduce the reservoir's productivity. When studying the lubricity performance of lubricants, it is imperative to evaluate the impact of the lubricants on formation damage through core flooding experiments.

Extensive literature studies have been performed to examine the effect of different nanoparticles on the lubricity of different base oils.[12-13] The analysis results show the potential of nanoparticles to improve lubrication. The nanoparticles' chemical composition, size, shape, and hardness are among other properties that determine their lubricity performance in the base oil. The presence of nanoparticles may therefore add value in terms of improving the lubricant film layer with rolling and mending effects at the damaged surface.

CONCLUDING REMARKS

Rheology and Tribology are important fields of study when designing oil well fluids such as drilling fluid and intervention fluids. Due to mechanical interactions, tubular surface damage increases the surface roughness and hence will increase the friction resistance of the motion. Enhancing the lubricity of the well fluids reduces the wear rate and minimizes torque and drag. As a result, it ensures minimized tubular integrity issues and allows reaching the target depth.

The study presented in this paper has shown the impact of the lubricants significantly reducing the coefficient of friction of the base oil. Moreover, results showed that the lubricity effect of the different lubricants varies a ' U' shape (non-linear) with concentration. Wei et al. also observed similar behavior.[15] Under realistic operational and downhole conditions, it is crucial to characterize lubricant tribological and film structural integrity properties as well as ensure that the lubricant will not cause formation damage.

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