Tribex™ ERD Additive

Technical Bulletin

Abstract

Tribex™ ERD Additive is a novel solid-state lubricant engineered in accordance with the principles of Tribology whose friction reduction is generated through Elastohydrodynamic lubrication (EHL), boundary, and mixed regimes of the Stribeck curve. Tribex™ ERD Additive is designed to overcome the performance limitations of commercial liquids and minimize material inconsistencies. Tribex™ ERD Additive is a multifunctional, multipurpose, solid-state lubricant that functions in both aqueous and non-aqueous formulations. Tribex™ ERD Additive exhibits very stable suspension properties and creates a stable lubricating film that minimizes contact between the formation and drilling assembly in critical Extended Reach Drilling applications.

Understanding Tribology

Tribology is the science of lubrication, friction and wear. The coefficient of friction (COF) is not a material property. It is a tribology system property. The system is unified, in which all factors are codependent. These factors include: type of material, coating, lubricant, size of contact area, geometry, stress, and surface roughness.

The role of the additive is to:

- Reduce friction
- Prevent/minimize wear on drilling assembly
- Efficiently transport cuttings away from the bit face (low gravity solids)
- Minimizes heat stress due to friction

Tribex™ ERD Additive reduces surface friction by forming a stable and durable film between the metal and wellbore interface through EHL. This filming mechanism leads to a reduction in wellbore asperities. A smooth surface in the wellbore allows the low gravity solids (LGS) to slide rather than stay in the wellbore contributing to hole cleaning efficiency and translated into a reduction of COF (the lubricating film is less contaminated).

Lubricant Effectiveness

The two key factors of drill string lubrication are (1) fluid shear properties (pressure viscosity index) and (2) chemistry (interaction with the surface, boundary-film forming properties, increased pressure profile, shear strength of solid and lubricant coating. The factors above have been considered while designing Tribex™ ERD Additive solid-state lubricant.

Elastohydrodynamic Lubrication (EHL)

Tribex™ ERD Additive uses the tribology principles of EHL to achieve the lowest COF. The weight-on-bit (WOB) and bottomhole assembly (BHA) cause elastic deformation through the wellbore/filter cake. This creates the proper conditions for EHL. A thin film of solid lubricant generates a high pressure viscosity increase pushing the BHA away from the wellbore interface. The absorption and adsorption properties of Tribex™ ERD Additive causes its to stick to the wellbore and metal by the rotation of the drill bit. A very small volume of fluid will remain in the high pressure contact area. This builds a continuous film layer.

Lubricity and Hydroplaning

The well known hydroplaning phenomena is a valid comparison to the lubrication mechanism. The water pressure causes the vehicle to rise up and slide on top of the thin layer of liquid between the tires and the road. Essentially, the water acts as a lubricant to the rubber. While drilling horizontally, the goal is to reduce friction and wear by building a thin and functional lubricated film. The function of the film is to separate the drilling assembly from the wellbore. This also keeps oil-based mud (OBM) in front of the bit. **Figure 1** illustrates functionality of the film.

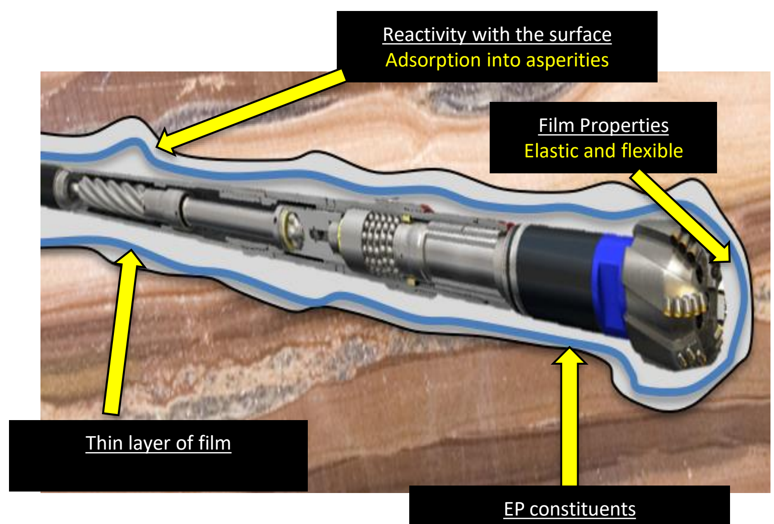

Figure 1 – *Film Functionality*

The figure below illustrates the EHL of Tribex™ ERD Additive:

- Small contact region
- High pressures (145K to 580K lbf/$in.^2$)
- Elastically deformed surfaces
- Solid lubricated films

The Journal bearing has a similar function as the drill bit rotating in the horizontal section. The converging surfaces are formed by virtue of the fact that they are concentric. When the drill bit or bearing rotates, it drags the fluid into the converging region, creating the Elastohydrodynamic pressure that separates the surfaces.

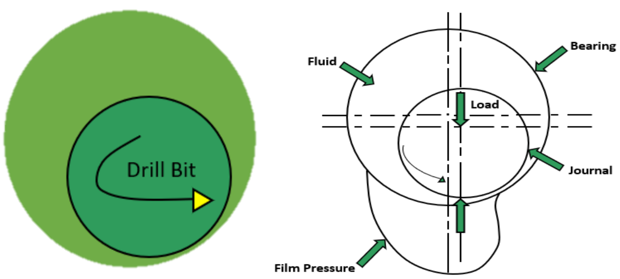

Figure 2 *– Friction fundamentals of Journal bearing are similar to rotating drill bit*

Design

As soon as the drill bit starts rotating, viscous molecules become chemically attached to the drilling assembly and the wellbore. The hydrodynamic pressure that appears in the inlet of the contact area will propagate further into the wellbore. The weight of the BHA will cause small deformation to the wellbore and the pressure of the EHL will carry the entire load. A very low rpm is enough to experience sliding against the wellbore when the surfaces are completely separated by the film fluid. The force needed to shear the fluid layer is far lower than the force between the wellbore and metal in the absence of the film. **Figure 3** below illustrates this concept:

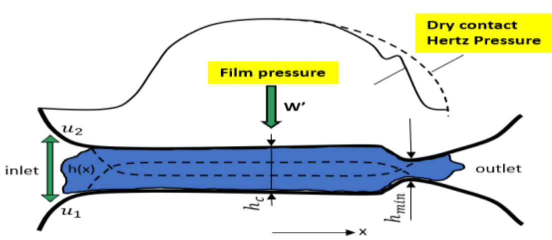

Figure 3 *– Design of Tribex™ ERD Additive*

Lubricity Tests

Tribex™ ERD Additive was tested in a 90/10 OWR Gibson base fluid by adding 2 and 3 ppb of solid lubricant. The results are indicated in **Figure 4**.

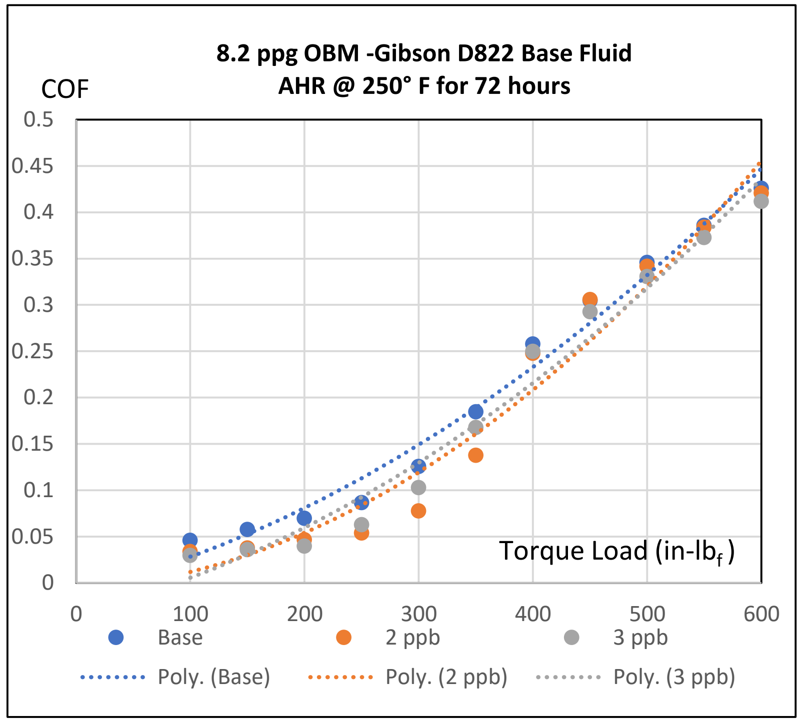

Figure 4 *– Lubricity Test Results*

Observe the decrease of COF with 2 ppb of Tribex™ ERD Additive. The formation of the thin film is in agreement with the deflection of the COF vs. torque loads. This illustrates Tribex™ ERD Additive for torque load in the 100 to 350 in-lb. range. The torque load pressure increases the film stability.

Solid Lubricant vs. Liquid Lubricant

Tribex™ ERD Additive adsorbs onto the wellbore asperities using the elasticity and flexibility of the lubricant, which lowers shear stress. Other liquid lubricant alternatives do not adsorb into the asperities of the wellbore and lack physically charged mechanisms that reduce the COF. Tribex™ ERD Additive, being a solid lubricant, is mostly insoluble in base oil/invert emulsion. The viscoelastic solid dispersed in the liquid phase provides a viscosity response which produces the hydrodynamic force that pushes the drilling assembly through the wellbore. This reduces COF and wear. Due to very high pressures at the contact interface, EHL involves elastic smoothing of the surface micro-asperities. This mechanism and an increase in viscosity ensure EHL continuity of the fluid film between the wellbore and the drilling assembly. See **Figure 5** and **Figure 6**.

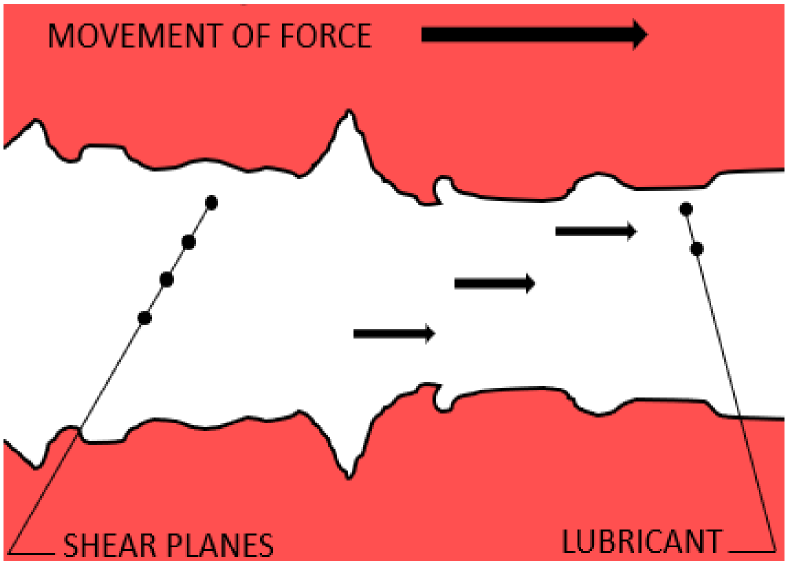

Figure 5 - *Solid lubricant*

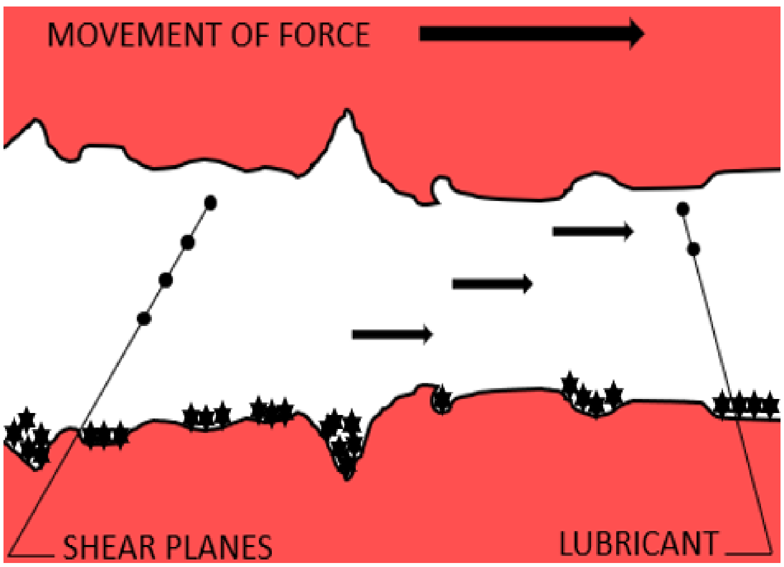

Figure 6 - *Solid lubricant with elastic and deformable properties*

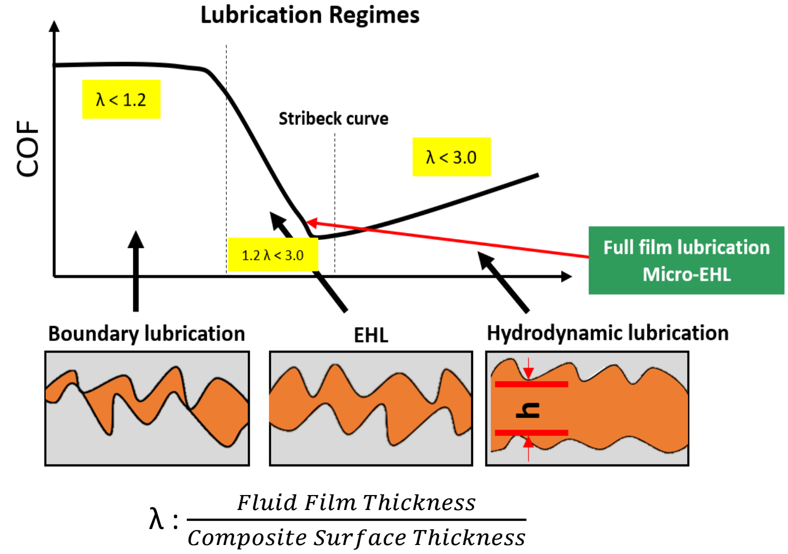

Figure 7 – *Stribeck Curve*

Lubrication Regimes

A film forms on both surfaces (wellbore and metal) when the lubricant is dispersed in OBM. The thickness of the film related to the asperities of the surface (λ) determines the effectiveness of the lubricant. The Stribeck curve illustrates the behavior of the COF as a function of rotation, the thickness of the film compared to the surface asperities, and the viscosity of the film formed between the surfaces in contact. See **Figure 7** for further explanation.

The COF is high when the surfaces are almost in contact with the thin film in relation to the size of the asperities. As soon as the film thickness increases, the surfaces have less contact. This causes the COF to be reduced. The COF continues decreasing to a minimum. A combination of EHL, proper balance of film thickness, asperity size (λ), and film stability enhances the adsorption of the solid lubricant. As the thickness of the film increases, the COF increases as a consequence of internal friction effects in the film. Tribex™ ERD Additive reduced the COF in the boundary mixed and EHL lubrication regimes.

Lubricity Evaluation Monitor (LEM) Testing

An LEM is a tool designed to analyze lubricants by direct comparison. A rotating steel bob measures the COF by pressing itself against the sample while submerged in a circulating cup of test fluid. The data is recorded in 10 second increments. Tribex™ ERD Additive and a liquid lubricant were tested on an LEM. See **Figure 8** and **Figure 9** for an illustration of the results.

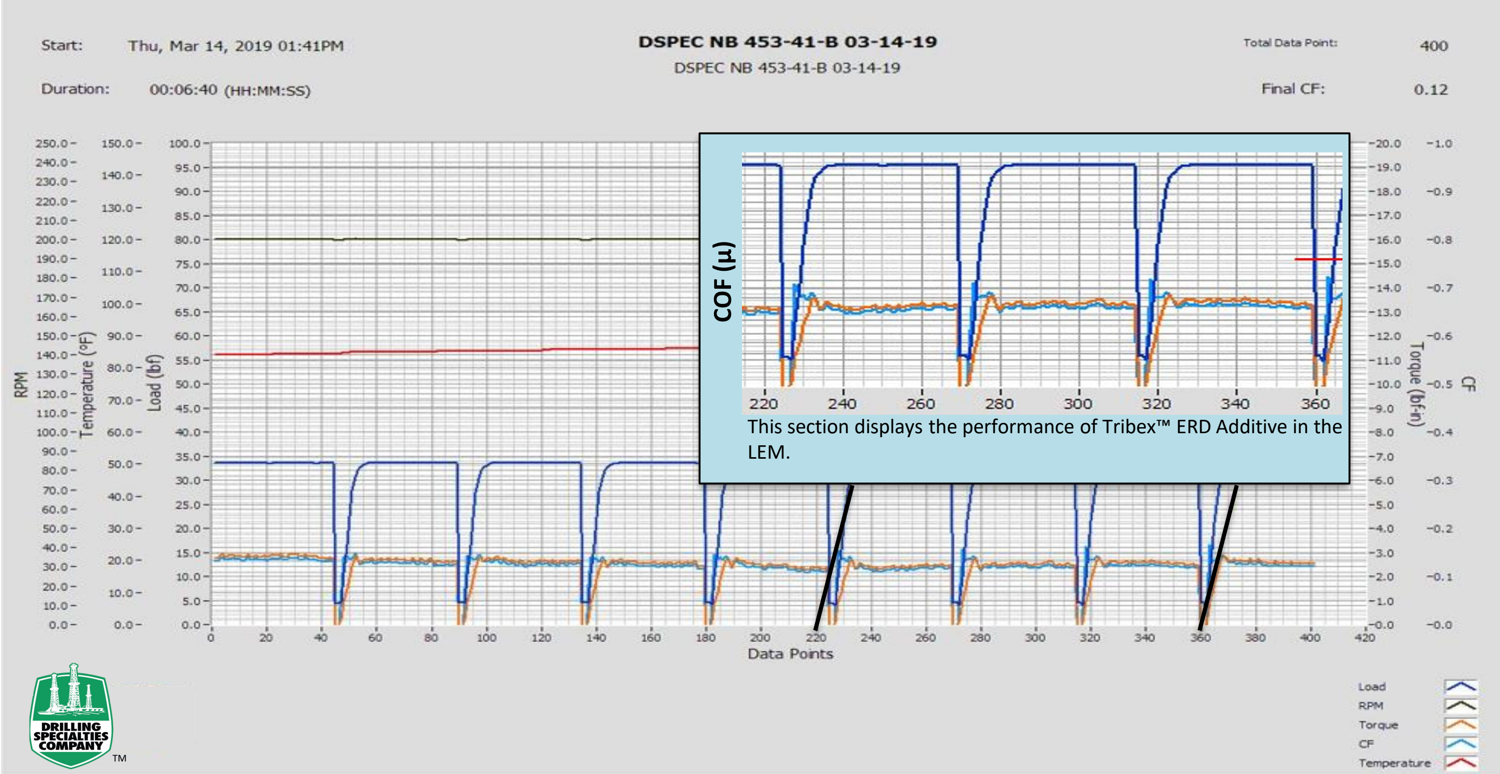

Figure 8: *Tribex™ ERD Additive*

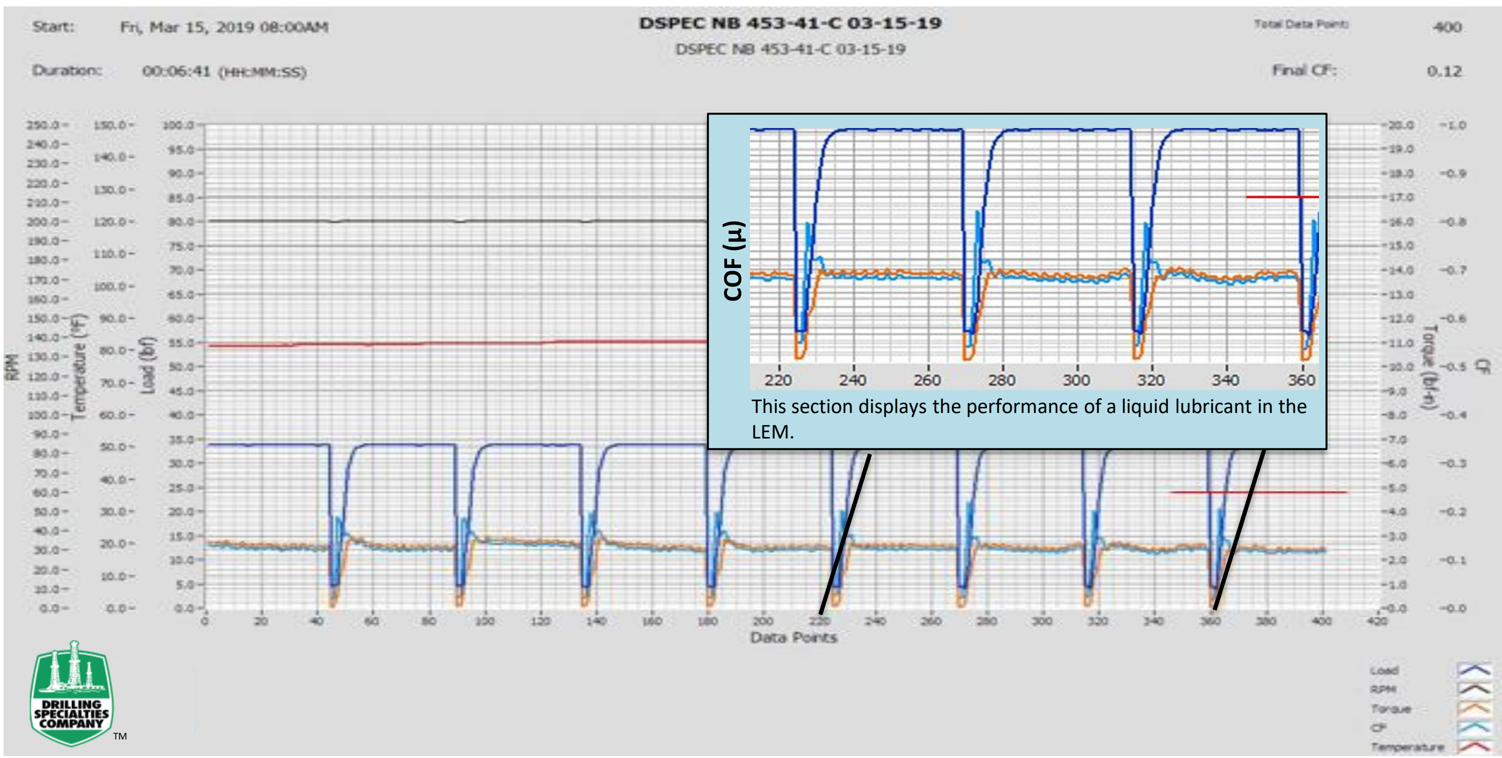

Figure 9: *Liquid Lubricant*

The lubricity curves of Tribex™ ERD Additive are compared with a liquid lubricant. Although the COF is the same, the peaks on the Stribeck curves of the liquid lubricant are significantly higher when compared to Tribex™ ERD Additive solid lubricant. Each single curve is a stage of the test. The initial peak represents the COF of the dry boundary lubrication when the cylinder begins moving. The peak COF is about 0.20 for the liquid lubricant, and 0.15 for Tribex™ ERD Additive. Each stage of the curve displays a Stribeck curve, which can be better studied by using the tribometer.

Stribeck Curve of Tribex™ ERD Additive

The Stribeck curve of the base fluid (BF) and the BF with 2 ppb of Tribex™ ERD Additive were built by using a tribometer. A tribometer performs repeatable friction/wear testing that can be done in rotative and linear modes that are compliant to ISO and ASTM standards. The tribometer provides a range of rotational speeds from 0.01 to 15,000 rpm. Data can be accurately recorded at any specific interval of time or position. This is a unique lubricity test because it provides a full and continuous spectrum of the COF.

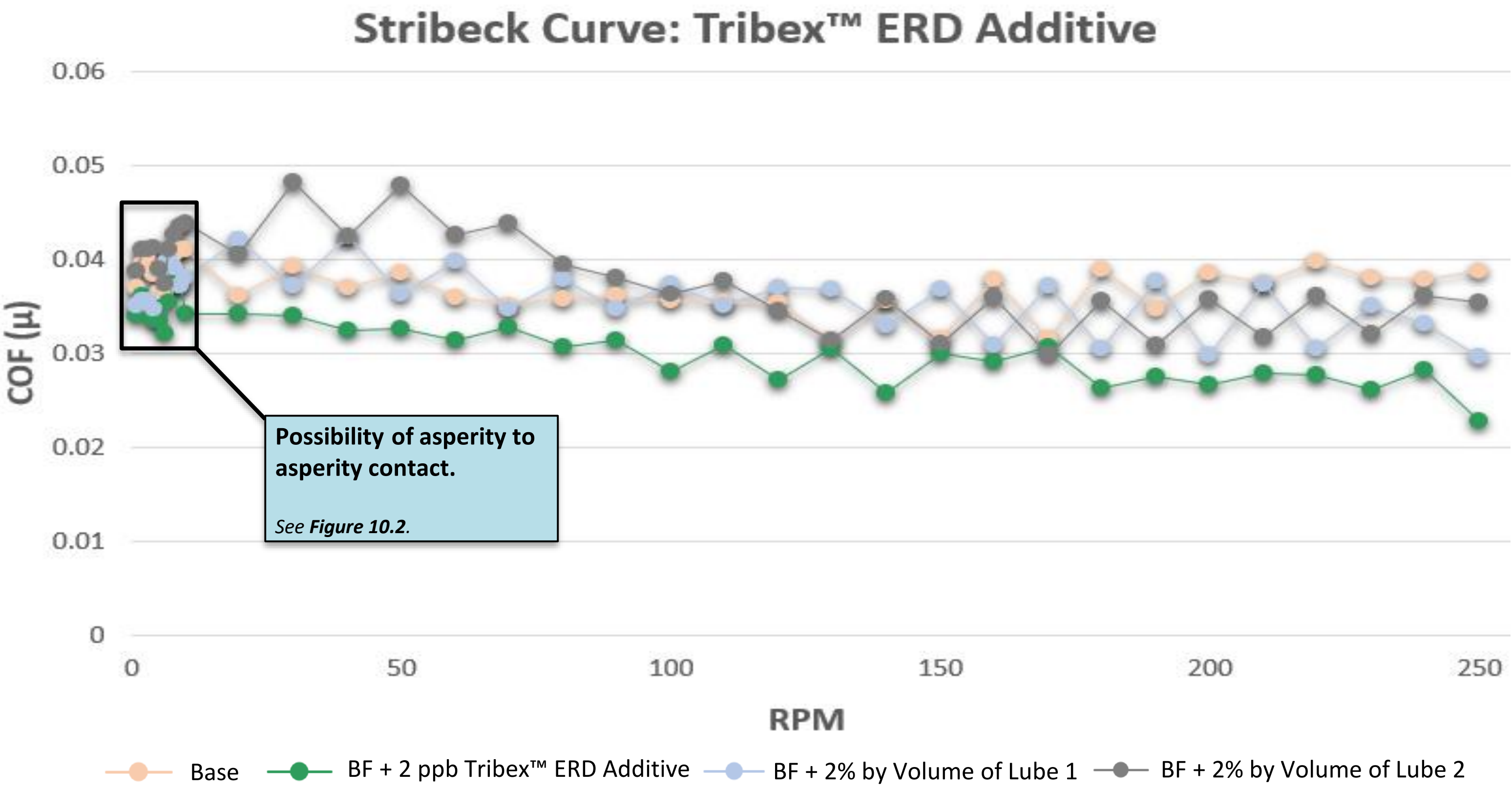

Figure 10.1 – *Stribeck Curve of Tribex™ ERD Additive Using A Tribometer*

A comparison of the following samples are illustrated in **Figure 10.1**: BF, BF + 2 ppb of Tribex™ ERD Additive, BF + 2% by volume of liquid lubricant 1 and BF + 2% by volume of liquid lubricant 2. The curve was built by extracting values from the data within the RPM range of 1 - 250. Notice the lower COF of Tribex™ ERD Additive when compared with the two liquid lubricants. The Stribeck curve for Tribex™ ERD decreases continuously while increasing the RPM. The liquid lubricants remain relatively stable.

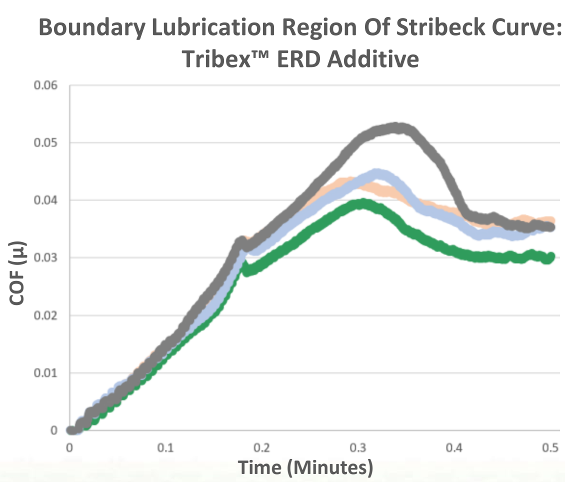

Figure 10.2 – *Boundary Lubrication*

Boundary Lubrication

Boundary lubrication is a lubrication regime defined by a film under constraints where the asperities are extremely close together that reasonable contact between opposing asperities is possible. Friction regimes are governed primarily by:

- f(x) = rotation
- f(x) = thickness of film as compared to surface asperities
- f(x) = viscosity of film between surfaces

Figure 10.2 illustrates the first 30 seconds of the friction and wear testing with the tribometer. The COF for Tribex™ ERD Additive (green line) peaked at about .04. The other test samples peaked at a higher COF.

Wear Testing With A Tribometer

The tribometer can measure the maximum and mean depth by examining the wear that is present inside the disc. As the pin rotates, the tip produces a rotative wear track. Friction and wear values are calculated continuously. Notice the finger print in **Figure 12**.

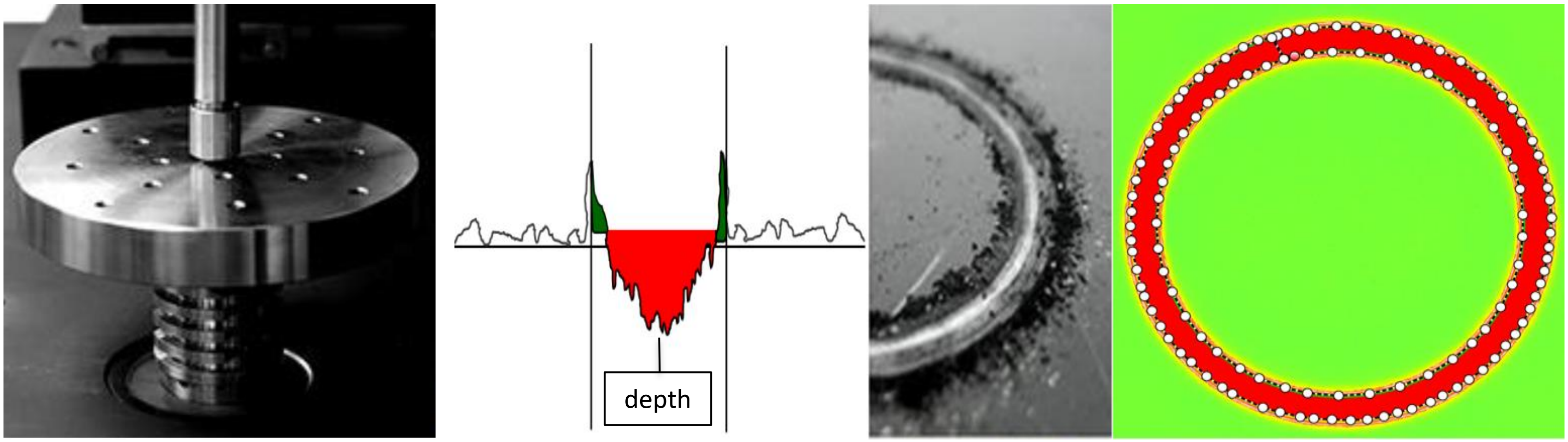

Figure 12 ***–*** *T2000 Tribometer*

Tribology Wear Tests

In **Figure 13**, the COF of Tribex™ ERD Additive was compared with the following samples: BF, BF + 2 ppb of Tribex™ ERD Additive, BF + 2% by volume of liquid lubricant 1 and BF + 2% by volume of liquid lubricant 2. The curve was built by extracting values from the data with 250 rpm and 670 N load. Notice the low COF of Tribex™ ERD Additive with the increase of rpm. The BF with no lubricants experienced a significant increase of wear.

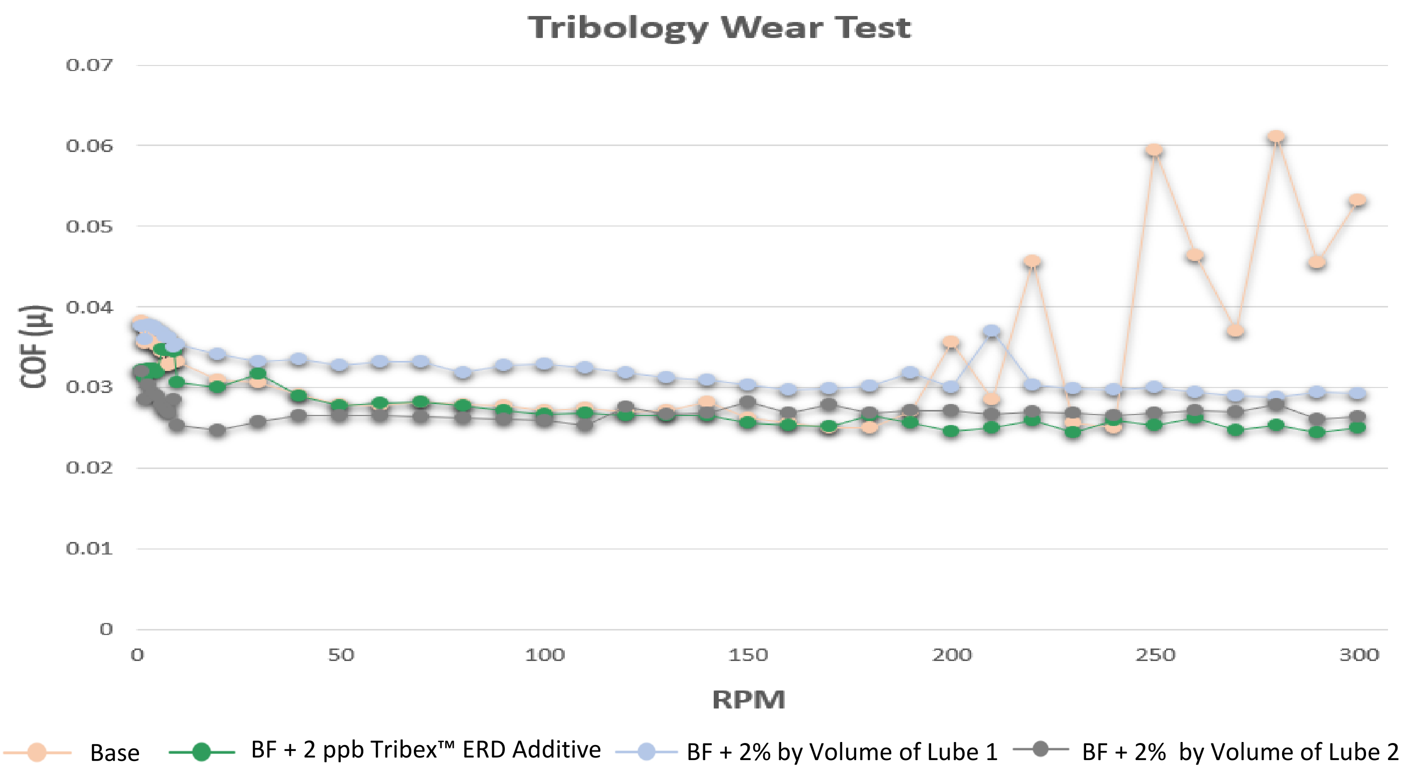

Figure 13 – *Stribeck Curve – Wear Test*

Figure 14 illustrates another comparison of the BF containing 2 ppb of Tribex™ ERD Additive vs. commercial lubricants. Tribex™ ERD Additive minimized the amount of wear, which is supported by the shallow finger print that was present inside the disc.

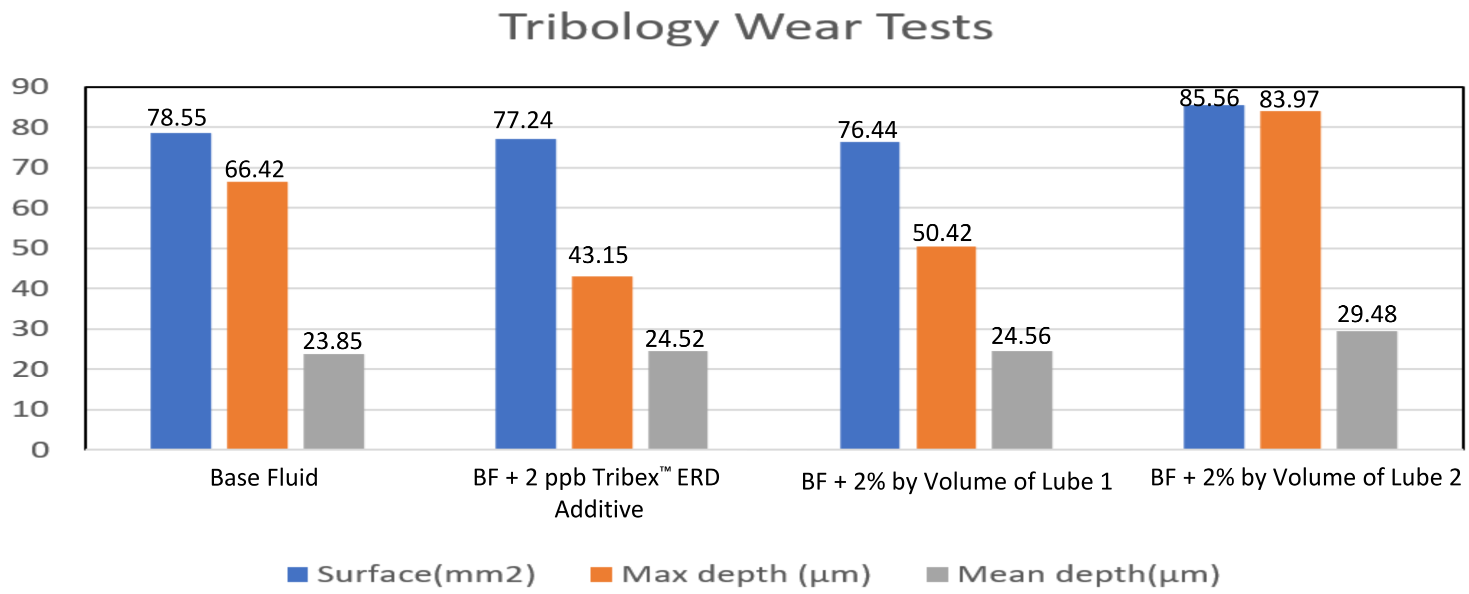

Figure 14 – *Wear Test Results*

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