RECENT ADVANCES IN TESTING THE LUBRICITY OF DIESEL FUELS

The term lubricity is often defined as the ability of a fluid to minimize the degree of friction and/or damage between surfaces in relative motion under load conditions, in this case, diesel fuel [1,2]. Friction represents a significant waste of power where when lubricity is not at a satisfactory level, then many internal engine components, including fuel pumps and injectors, are prone to excessive wear and metal damage. The resultant wear and tear leads to inefficient performance, shortened service life, and high replacement costs. As the Environmental Protection Agency (EPA) continuously enforces new emissions standards for diesel fuels, the importance of adequate fuel lubricity has increased since critical engine parts must perform at evermore demanding operating pressures and temperatures and, consequently, with greater degrees of metal-to-metal contact. Good lubricity quality is of utmost importance to engine manufacturers and users alike, increasing the need to test for diesel lubricity.

The EPA began regulating diesel fuel sulfur levels in 1993 [3]. Before regulations began to take place, diesel fuel contained as much as 5,000 parts per million (ppm) of sulfur. In 2006, the EPA began to phase in more stringent regulations to lower the amount of sulfur in diesel fuel to 15 ppm [3], where this fuel is known as ultra-low sulfur diesel (ULSD). Diesel fuel is obtained from crude oil, which contains a considerable percentage of sulfur compounds, like sulfur gases such as SO2 that when emitted can affect the environment, where its refining cannot assure the complete removal of sulfur in the final fuel [4]. After combustion in the engine, the sulfur in fuel forms particulates that are the primary contributor to air pollution and the cause of harmful corrosion in the engine [5]. Global efforts to improve air quality have dramatically reduced the allowable sulfur content in diesel fuel, which helps reduce climate change but in doing so also means that the composition of the fuel must change. Refineries removing large amounts of sulfur from diesel through hydrotreating methods have shown that any significant reduction in sulfur content would result in a significant reduction in fuel lubricity as well [6].

The lubricity of a substance cannot be measured directly as it is not a material property, rather tests can be performed to quantify a lubricant's performance for a specific system. Generally, the tests used to evaluate diesel fuel lubricity try to create conditions of boundary lubrication. Several bench tests that try to recreate boundary lubrication conditions, like those found in fuel injection equipment, have been developed to allow rapid and relatively inexpensive measurements of fuel lubricity. The Ball-on-Cylinder Lubricity Evaluator (BOCLE) has emerged as the most significant test to measure the lubrication properties of aviation turbine fuels in the 1980s when it was first used as a lubricant research device modified for low viscosity jet fuel when the Air Force encountered fuel control problems in 1965 with JP-4 [7]. It is particularly useful for measuring the effects of fuels and additives on oxidative wear, an important wear mechanism in aviation fuel systems. In the mid-1990s, the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE) [8] was developed as a reaction to fuel system failures due to the introduction of reduced sulfur content in diesel fuels. This testing method holds similarities to the BOCLE test but with modifications to make it less sensitive to oxidative wear and more sensitive to adhesive scuffing. In 1997, the SLBOCLE test was standardized by ASTM D6078, however, this testing method has been withdrawn in 2021 [9]. Lastly, the High-Frequency Reciprocating Rig (HFRR) was also developed in the 1990s to make it useful for evaluating diesel fuel, where a wide range of wear mechanisms depending on the fuel being tested can be produced. This testing method was standardized by ASTM D6079, which was first published in 1999.

In 2005, the ASTM D975 lubricity specification [10] went into effect after concerns over the loss of lubricity with the new ULSD fuel, where lubricity was determined by rubbing a metal ball on a flat disc submerged in the fuel being tested to determine scarring and wear [11]. Among all testing methods mentioned prior, the HFRR has shown to be more commonly used to assess the lubricity of diesel fuels, as the SLBOCLE became less popular when the ASTM D975 diesel specification set a standardized value for lubricity. The Standard Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR) [12] may be used to evaluate the relative effectiveness of diesel fuels for preventing wear under the prescribed test conditions [13,14]. This test method is designed to evaluate boundary lubrication properties as diesel fuel injections equipment has some reliance on lubricating properties of the diesel fuel, where shortened life of engine components has sometimes been ascribed to lack of lubricity in diesel fuel. Due to the compositional changes to fuels and the need to introduce lubricity improvement agents into fuels, ASTM D6079 has proven to be a robust and reliable test method to measure and monitor the lubricity of diesel fuel.

The HFRR by Koehler Instrument Company, Inc. is a versatile computer-controlled apparatus for evaluating the lubricity of diesel fuels conforming to ASTM D6079 and related specifications [15]. Reciprocation motion occurs between the fixed stationary counter surface material mounted on a small lubricant bath and reciprocating (ball) frequency, displacement, and normal load is selected according to test equipment. Figure 1 showcases a HFRR unit developed by Koehler. One of the advancements of Koehler's HFRR is the development of the closed-loop PID controller. Currently underutilized by most of the market, the closed-loop PID controller consists of a micro-controlled based controller module and application software. This controller is responsible for monitoring the vibrational and reciprocating motion of the upper specimen. Koehler's HFRR system response is also improved to reduce system harmonics, which influence many of the friction

Figure 1: A High-Frequency Reciprocating Rig (HFRR) [15].

force measurement systems of other HFRR units. The system reduces this effect by applying filtering to the raw frictional forces data which allows for a more accurate and effective understanding of the frictional forces. These advancements allow for a deeper understanding of the test system and can lead to more comprehensive conclusions drawn from lubricity testing.

Diesel fuel injection pumps are known to be lubricated primarily by the fuel itself, where the fuel viscosity is used as a rough indicator of a fuel's ability to provide wear protection [16]. Since the introduction of the EPA's diesel standards to reduce harmful emissions from both on-road and nonroad diesel sources by more than 90% and the advent of low sulfur diesel, even some fuels of higher viscosity have been found capable of producing wear. Lubricity is of great importance due to the fine tolerances of the components within the fuel-injection system, some of which are measured in ten-thousands of an inch. If a fuel's lubricity is too low, improper lubrication will shorten the service life of fuel injectors and high-pressure pumps. Through the introduction of different tests to efficiently monitor lubricity performance the HFRR has shown to be a good indicator of diesel lubricity performance. Recent advancements in equipment using HFRR to test for the lubricity of diesel have shown to improve results and data that can help avoid engine failure, minimize the number of expensive repairs performed, and ensure the quality of the diesel fuel.

Authors

Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 27 years. He is an elected Fellow by his peers at IChemE, CMI, STLE, AIC, NLGI, INSTMC, Institute of Physics, The Energy Institute and The Royal Society of Chemistry. An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, "Fuels and Lubricants handbook", details of which are available at https://bit.ly/3u2e6GY

He earned his doctorate in Chemical Engineering from The Pennsylvania State University and is a Fellow from The Chartered Management Institute, London. Dr. Shah is also a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute and a Chartered Engineer with the Engineering council, UK. Dr. Shah was recently granted the honorific of "Eminent engineer" with Tau beta Pi, the largest engineering society in the USA. He is on the Advisory board of directors at Farmingdale university (Mechanical Technology), Auburn Univ (Tribology) and Stony Brook University (Chemical engineering/ Material Science and engineering). An Adjunct Professor at the State University of New York, Stony Brook, in the Department of Material Science and Chemical engineering, Raj also has over 500 publications and has been active in the petroleum industry for over 3 decades.

More information on Raj can be found at https://bit.ly/3sayVgT

Ms. Alexandra Przyborowski is an honour student of Chemical engineering at SUNY, Stony Brook University graduating in the summer of 2022, and currently has been working as a technical intern at Koehler Instrument Company, in Long Island, NY for the last two years.

References

[1] Staff, The. "Taking the Mystery out of Lubricity: Fuel Oil News." Fuel Oil News | Serving The Deliverable Fuels Industry, 3 Mar. 2010, https://fueloilnews.com/2010/03/04/taking-the-mystery-out-of-lubricity/.

[2] "Fuel Property Testing: Lubricity." Fuel Property Testing: Lubricity, https://dieselnet.com/tech/fuel_diesel_lubricity.php.

[3] "Diesel Fuel Standards and Rulemakings." EPA, Environmental Protection Agency, https://www.epa.gov/diesel-fuel-standards/diesel-fuel-standards-and-rulemakings.

[4] Tahseen Hameed Khlaif and Asaad Salim Bded 2019 IOP Conf. Ser.: Mater. Sci.

Eng. 579 012012

[5] "How Sulfur Content in Diesel Fuel Impacts Engine Oil Formulation." Lubrizol360.Com, https://360.lubrizol.com/2019/How-Sulfur-Content-in-Diesel-Fuel-Impacts-Engine-Oil-Formulation#:~:text=Diesel%20fuel%20contains%20sulfur%20which,harmful%20corrosion%20in%20the%20engine.

[6] "Understanding Ultra Low Sulfur Diesel Fuel." Kendrick Oil, 4 May 2020, https://kendrickoil.com/understanding-ultra-low-sulfur-diesel-fuel/.

[7] Dukek, W. G. "Ball-on-Cylinder Testing for Aviation Fuel Lubricity." SAE Transactions,

vol. 97, SAE International, 1988, pp. 475–82, http://www.jstor.org/stable/44471549.

[8] "Standard test method for evaulting lubricity of diesel fuesl by scuffing load ball-on-

cylinder lubricity evaluator (SLBOCLE)". (ASTM standard). United States: N. p., 1997. Web.

[9] "Standard Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE) (Withdrawn 2021)." ASTM International - Standards Worldwide, https://www.astm.org/d6078-04r16.html.

[10] "Specification for Diesel Fuel." https://doi.org/10.1520/d0975-21.

[11] Exceeding Expectations - Amspecllc.com. https://www.amspecllc.com/wp-content/uploads/2017/09/amspectechtalk-dieselfuellubricity.pdf.

[12] "Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)." https://doi.org/10.1520/d6079-18.

[13] "ASTM D6079 - Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)." Savant Labs - Testing Lab for ASTM D6079 - Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR), https://www.savantlab.com/astm-method/savant-labs-astm-d6079-evaluating-lubricity-of-diesel-fuels-by-the-high-frequency-reciprocating-rig-hfrr/.

[14] "ASTM D6079." ASTM D6079 : Standard Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR), https://global.ihs.com/doc_detail.cfm?document_name=ASTM+D6079&item_s_key=00284095.

[15] " High Frequency Reciprocating Rig (HFRR) ." Koehler Instrument Company, Inc., 14 Aug. 2019, https://koehlerinstrument.com/products/high-frequency-reciprocating-rig-hfrr/?search=high+frequency&description=true&sub_category=true.

[16] Barbour, R. H., et al. "Understanding Diesel Lubricity." SAE Technical Paper Series, 2000, https://doi.org/10.4271/2000-01-1918.

Author Contact Details

Dr. Raj Shah, Koehler Instrument Company • Holtsvile, NY 11742 USA • Email: rshah@koehlerinstrument.com • Web: www.koehlerinstrument.com

Alexandra Przyborowski, SUNY, Stony Brook University •

Alexandra Przyborowski

Raj Shah

Read, Print, Share or **Comment** on this Article at: **petro-online.com/Article**