LUBRICANT PROPERTIES AND LABORATORY TEST TECHNIQUES THAT ARE SPECIFICALLY ESSENTIAL TO ELECTRIC VEHICLES

It is impossible to deny that over the past two decades, electric vehicles (EVs) have seen a drastic increase in popularity among consumers. Consumer spending on electric cars in 2020 totaled $120 billion, a 50% increase compared to 2019, with quickly expanding markets in China, Europe, and the United States. EVs have advantages such as a 10 cent per mile lower operating cost than traditional internal combustion engines (ICEs), lower greenhouse gas emissions, and performance benefits that have made EVs incredibly appealing to the general public. This fast ascent to relevance for EVs has put some of the largest corporations in the automotive industry such as Mercedes-Benz, Ford, Honda, and Volvo on notice since they have all made promises to make a complete transition towards only producing EVs by 2030.

Furthermore, many areas of the world have begun shifting future infrastructure plans to better accommodate EVs as legislation to phase out ICEs has slowly gained popularity among legislators. However, a complete overhaul of the automotive industry would prove to be difficult as EVs require a very high degree of specialization in their lubricants to function. With EVs being still relatively new, there is still much to learn on how to fully optimize the performance of the electric engine, and new types of lubricant formulations are tested every day to attempt to do so. For these reasons, it is vital to understand the specifications and test methods for EV lubricants and how they drastically vary from those of ICE vehicles.

The first main difference is the need for the EV lubricant to react well when in contact with the electrical components of the motor. The lubrication for ICE vehicles has never had to be adjusted for this problem as all of the components receiving lubrication did not have any electrical components for the lubricant to come in contact with. In EVs, many components such as electric modules, cable insulations, sensors, and circuits come into contact with lubrication. For this reason, the lubrication must be able to come into contact with the copper in these mechanisms without corroding it. To test for this compatibility ASTM D-4048 is employed to analyze and measure the amount of corrosion caused by the lubricant on a copper strip. The test begins by first polishing a copper strip sample and completely immersing the copper test strip into a tightly packed grease sample heated in an oven at 100 °C (±1 °C) for 24 hours (± 5 minutes). After the test is complete, the copper strip is removed, wiped down to remove excess grease, washed off with acetone, and visually compared to the ASTM Copper Strip Corrosion Standards to find the degree of corrosion. The test ranges include freshly polished, slightly tarnished (1a to 1b), moderately tarnished (2a to 2e), dark tarnish (3a to 3b), and corrosion (4a to 4c), with the lower number ratings being more desirable. Typical lubricants often contain a sizeable amount of sulfur as sulfur is known to have positive lubricating effects. The high amounts of sulfur not only negatively affect the environment but is also a main reason copper corrosion occurs. Copper corrosion is most commonly caused by the presence of copper sulfide, typically formed when the sulfur components of the lubricant interact with copper surfaces. The corrosion leads to the formation of wet films on the electrical components, creating electrical failures. This test has recently been updated to be performed on a copper wire instead so that it more accurately represents what the lubrication will be coming in contact with. This test is vitally important as lubrication is often used on parts such as bearings that contain copper or copper alloys where any excessive corrosion on the bearings can cause premature bearing failures leading to lots of damage to the machine.

A second difference between the testing methods for EV and ICE lubrication is the test for high-speed foaming. Whereas standard ICEs hover around the range of 1500-3000 rpm, electric motors are designed to be compact to save weight and space, making higher rotational speeds of up to 18,000 rpm a possibility. Under these high rpm conditions, the motor is under great stress, which can cause fluids to foam and damage the surfaces of the components. The foaming occurs because of excessive agitation to the lubrication caused by the high rpm of the motor, which can result in a compositional breakdown of the lubricant, separating the grease component from the other additives. This then allows for air to infiltrate the lubricating oil, forming foam. This foaming could theoretically happen in ICEs as well; however, due to the drastically greater rpm's the electric engine creates, the foaming is much more prevalent and therefore much more important to test for in EVs. The Foam Test, ASTM D-892, is performed by placing two samples of the lubricating greases in a diffuser at two pre-established temperatures 24 °C (± 0.5 °C) and 93.5 °C (± 0.5 °C). Air is then blown through the samples at a constant and controlled rate of 94 mL/min (±5 mL/min) for 5 min and allowed to settle for 10 minutes. Foam height and volume is measured at the end of both periods and the final foaming tendency is reported as a series of values starting with the volume of foam (in mL) after 5 minutes of blowing air through the oil, followed by the volume of foam (in mL) after 10 minutes without air. This test is vital for EVs as a lubricant with insufficient resistance to foaming can cause cavitation. Cavitation is the formation of air bubbles in the fluid due to the lowering of the pressure in a liquid, which then implodes in the higher-pressure regions of the system. This implosion can be powerful enough to create holes or pits in even hardened metal if the implosion occurs close to the metal's surface. Foaming also increases the volume of the lubricant which can lead to numerous undesirable effects. Firstly, the increase in volume usually decreases both the performance and life of the lubrication, which negatively impacts the efficiency of the EV. Secondly, the increase in volume can lead to overflow resulting in a significant loss of lubrication which results in components being insufficiently lubricated leading to mechanical failure.

A third difference between the testing methods for EV and ICE lubrication is the need to test for dielectric strength and breakdown voltage. As many more components of the drivetrain (AC/DC inverter and converter, lithium-ion batteries, and the electric motor) have more advanced and higher voltage circuitry in EVs than in ICE vehicles, these measurements of electrical resistance are vital for EVs. Dielectric strength is defined by the maximum voltage required to break down a specific material and is tested through ASTM D-149. The dielectric strength test is performed by placing the test sample between two electrodes in air or oil. Voltage is then increased at a uniform rate from 0 to the dielectric breakdown point is reached, which can be observed by an electric burn-through or decomposition in the sample. Two alternate test methods also exist, the slow-rate-of-rise method and the step-by-step method. The slow-rate-of-rise method has the same setup but begins at 50% of the breakdown voltage and increased at a slower uniform rate. The step-by-step method also begins at 50% of the breakdown voltage, but from there the voltage is increased in equal incremental jumps rather than gradually increasing the voltage at a uniform rate. The final data is recorded in volts per unit thickness by dividing the recorded breakdown voltage by the thickness of the sample. Dielectric strength is pivotal as the high voltages and amps present within the circuitry of EVs would be harmful both to the materials of the vehicle and the operator if they came into contact. Having lubrication with high dielectric strength makes the lubrication act as an insulator of sorts, further separating the harmful currents from the operator. The dielectric breakdown voltage is defined by the minimum voltage that causes a portion of an insulator to become electrically conductive. This test is performed by ASTM D-1816 where mushroom-shaped electrodes (representative of the ones used in transformers) apply increasing amounts of voltage (from 0 increasing at a rate of .5 kV/s) to a liquid sample until five sequential breakdowns occur and then the calculated mean is the breakdown voltage. For the duration of the test, the test sample is being constantly stirred and circulated throughout the test cell to ensure the voltage is being applied evenly for accurate results. Dielectric breakdown voltage is also vital as it indicates the lubricant's ability to withstand electric stress without failure. In an EV, lubrication will regularly come into contact with electric currents, and if any decomposition occurs the lubricant can fail, causing damage to the machine.

The fourth and final main difference between the testing methods for EV and ICE lubrication is the test for the life of the lubrication at elevated temperatures in ball bearings. The temperature test is relevant for both EV and ICE vehicle lubricants; however, EVs operate with considerable temperature variations and with much higher torques compared to ICE vehicles. This higher torque correlates to more frictional force being applied to the components, generating more heat, resulting in a greater temperature range for EV lubricants. The test method, outlined by ASTM D-3336, begins with lubricating an SAE No. 204-sized ball bearing. This ball bearing is then rotated at 10,000 rpm under light load at a specified test temperature as high as 371°C until failure or completion of the specified run time. The main problem with this test is that it has not yet been properly adjusted to fit the needs of EV specifications. This test works as a good stress test for ICE vehicle lubrication as the ball bearings in that system are only usually subjected to 6000-10000 rpm. However, in EVs, the ball-bearing lubrication must endure up to 20,000 rpm making the range of the current standardized test insufficient. I would suggest a separate procedure for EV lubricants be created under the ASTM D-3336 regulations or for an entirely new test to be created to properly simulate the high rpm inside of an EV. This test is vital as lubrication must maintain its composition under high temperatures caused by friction and motor operation. If the lubricant were to decompose under these high temperatures, the lubrication would become unable to effectively protect the surface of the machinery. This would leave parts of the machinery under-lubricated, causing increased wear and damage.

As the performance of EVs continues to rise and as more corporations make the transition to EVs, it is becoming increasingly important to understand the higher degree of difficulty that comes with lubricating EVs. With the future of mobility shifting to electric testing methods regarding the lubrication of EVs must be adjusted. Due to the drastically greater rpm of the electric motor, tests for foaming, lubricity, and high-temperature performance must be more strenuous to accurately simulate the conditions the lubrication will be applied in. Furthermore, as EVs contain many more electrical components than their IC vehicle counterparts, the lubrication in EVs must also avoid corroding copper and prevent itself from acting as an insulator so that electric current is not carried to other mechanisms in the car or the operator. It is possible to develop lubrication that passes these unique and strenuous tests, but as the performance of EVs increase (possibly seeing ball bearing rpm increase to nearly 30,000 rpm by 2025), standardized tests will continuously need to be created and updated to accurately assess if the lubricant will survive in an EV.

Works Cited

TotalEnergies. "Lubricating Electric Vehicles." CNBC, CNBC, 28 Nov. 2020, www.cnbc.com/advertorial/2019/01/10/lubricating-electric-vehicles.html.

Van Rensselar, Jeanna. "Lubricants for Electric Cars and Trucks." MachineDesign, MachineDesign, 21 Jan. 2021, www.machinedesign.com/materials/article/21152956/lubricants-for-electric-cars-and-trucks.

"EVs Need Different Lubes." Lubrizol360.Com, Lubrizol360, 1 Oct. 2018, 360.lubrizol.com/2018/EVs-Need-Different-Lubes.

Shah, Raj, et al. "The New Age of Lubricants for Electric Vehicles." Electric & Hybrid Vehicle Technology International, Electric & Hybrid Vehicle Technology International, 7 Aug. 2020, www.electrichybridvehicletechnology.com/features/the-new-age-of-lubricants-for-electric-vehicles.html.

Chen, Yan, et al. "Performance Characteristics of Lubricants in Electric and Hybrid Vehicles: A Review of Current and Future Needs." Frontiers, Frontiers, 14 Oct. 2020, www.frontiersin.org/articles/10.3389/fmech.2020.571464/full.

Andrew, Jane Marie. "The Future of Lubricating Greases in the Electric Vehicle Era." www.stle.org, Stle.org, May 2019, lelubricants.com/wp-content/uploads/pdf/news/Articles/TLT_Electric%20Vehicle%20Grease_Sander_05-19.pdf.

Kavanagh, Laurence, et al. "Global Lithium Sources-Industrial Use and Future in the Electric Vehicle Industry: A Review." MDPI, Multidisciplinary Digital Publishing Institute, 17 Sept. 2018, www.mdpi.com/2079-9276/7/3/57/htm.

Shah, Raj, et al. "Standards and the Growth of Electric Vehicles." ASTM Standardization News, ASTM Standardization News, 9 Sept. 2020, sn.astm.org/?q=features%2Fstandards-and-growth-electric-vehicles-.html.

"Foam Test." TestOil, Routine Testing, 17 Oct. 2012, testoil.com/routine-testing/analyzing-foaming-tendency-foam-test/.

ASTM.org. "ASTM D3336-97R02." Scribd, Scribd, Mar. 2003, www.scribd.com/document/262699654/ASTM-D3336-97R02.

Shah, Raj, et al. "Grease Performance Requirements and Future Perspectives for Electric and Hybrid Vehicle Applications." Mdpi.com, MDPI, 6 May 2021, www.mdpi.com/2075-4442/9/4/40.

Van Rensselar, Jeanna. "The Tribology of Electric Vehicles." BearningNews.com, BearningNews, 7 June 2019, www.bearing-news.com/the-tribology-of-electric-vehicles-2/.

McKerracher, Colin. "EVO Report 2021: BloombergNEF: Bloomberg Finance Lp." BloombergNEF, BloombergNEF, 2021, about.bnef.com/electric-vehicle-outlook/.

Ahmed, Nehal S., and Amal M. Nassar. "Lubrication and Lubricants." IntechOpen, IntechOpen, 22 May 2013, www.intechopen.com/chapters/44826.

Tung, Simon C., et al. "Global Insights on Future Trends of Hybrid/EV Driveline Lubrication and Thermal Management." Frontiers, Frontiers, 20 Oct. 2020, internal-journal.frontiersin.org/articles/10.3389/fmech.2020.571786/full.

"Copper Corrosion Test (ASTM D-4048)." Newgate Simms Tech Support, Newgate Simms, 27 Nov. 2018, support.newgatesimms.com/copper-corrosion-test-astm-d-4048/.

Cusano, C M, and J C Wang. "Corrosion of Copper and Lead Containing Materials by Diesel Lubricants." Lubrication Engineering, OSTI.gov, 1 Jan. 1995, www.osti.gov/biblio/191836.

Valdez Salas, Benjamin, et al. "Copper Corrosion by Atmospheric Pollutants in the Electronics Industry." ISRN Corrosion, Hindawi, 2 Oct. 2013, www.hindawi.com/journals/isrn/2013/846405/.

Mfame Team. "Watch out – Foaming in Lubricating Oils!" Mfame.guru, 18 Mar. 2016, mfame.guru/watch-out-foaming-in-lubricating-oils/.

About the Authors

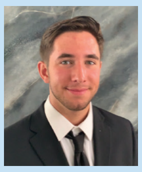
Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 25 years. He is an elected Fellow by his peers at IChemE, CMI, STLE, AIC, NLGI, INSTMC, The Energy Institute and The Royal Society of Chemistry An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, "Fuels and Lubricants handbook", details of which are available at

https://www.astm.org/DIGITAL_LIBRARY/MNL/SOURCE_PAGES/MNL37-2ND_foreword.pdf

A Ph.D in Chemical Engineering from The Penn State University and 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. An adjunct Professor at the Dept. of Material Science and Chemical Engineering at State University of New York, Stony Brook, Raj has over 400 publications and has been active in the Oil analysis field for 3 decades. More information on Raj can be found at

https://www.petro-online.com/news/fuel-for-thought/13/koehlerinstrument-company/dr-raj-shah-director-at-koehler-instrumentcompany-conferred-with-multifarious-accolades/53404

Alex D' Acunto is a student of Chemical engineering at SUNY, Stony Brook University, and currently works as an intern at Koehler Instrument Company, in Long Island, NY.



Alex D' Acunto

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

Author Contact Details

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