FUTURE TRENDS IN FUELS AND LUBRICANTS TESTING - PREPARE FOR THE CHALLENGES

The future of fuels and lubricants will be driven by sustainable development goals that includes e-mobility, sustainable biofuels and alternate energy sources. In this emerging landscape, laboratory testing is undergoing a transformation to enable product development and better quality control. The key challenges within these industries will be the development and standardization of test methods for e-lubricants and better precision in lubricity measurement of sustainable fuels.

AI enabled tools for accurate and precise fuel lubricity measurement

Renewable sources for producing diesel fuel include vegetable oils, waste cooking oils and animal fats among others sources. The second generation of Hydrotreated Vegetable Oils (HVO) have overcome the disadvantages associated with of FAME (fatty acid methyl esters) such as increased NOX emission and poor cold operability. HVOs (EN 15940 standard) are a class of renewable diesel that is close to fossil fuel diesel (EN 590 standard). High frequency reciprocating rig (HFRR), is a test developed in the early nineties which is the global standard for diesel fuels with strict fuel specifications to protect fuel injection system hardware. In the US the ASTM D975 limit is 520 µm, in Europe the EN 590 limit is 460 µm, while the World Wide Fuel Charter recommends a maximum wear scar of 400 µm. HVOs with insufficient lubricity introduced to injection equipment can result in noncompliance with ASTM D975 or EN 590 and hence are blended with anti-wear (AW) additives to comply with lubricity factor specified in D975 and EN 590. HFRR is used to screen AW additives compatible with HVOs and also for quality control of fossil fuel diesel blended with HVOs.

HFRR 4.2 (Figure 1) in accordance with ASTM D6079 and ISO 12156 can be used for testing these renewable fuels. It uses a unique ***salt-free humidity control system*** that was first introduced in 2020 and requires ***only distilled water,*** This is electronically controlled and offers a simpler and environment friendly integrated unit.

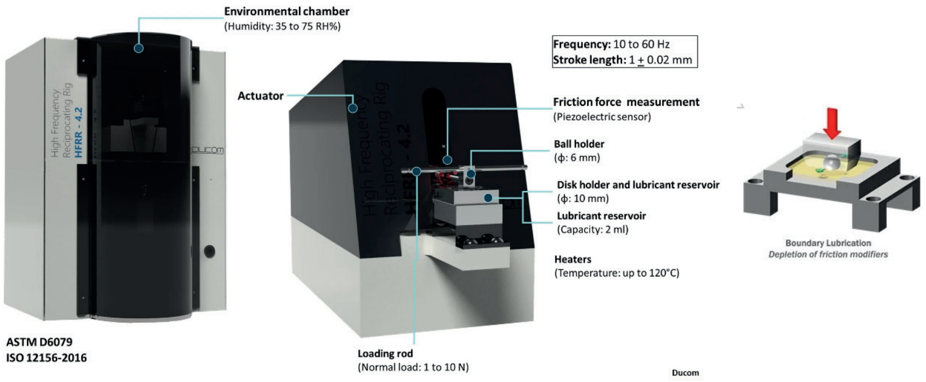


Figure 1 Automated HFRR 4.2 powered by AI wear scar measurement. Insert shows the test geometry.

The ball wear scar diameter (MWSD) was measured according to fuel lubricity test standards like ISO 12156-1 or ASTM D6079 to check HVOs compliance with EN 590 or D975. Ten samples of HVOs without AW additives and ten samples of HVOs with AW additives were tested. As shown in Figure 2, the average of ball MWSD for HVOs without AW additives was 618 µm (N = 10, precision of 33 µm) and for the HVOs with AW additives it was 399 µm (N = 10, precision of 26 µm). The wear scar measurement were done using our advanced artificial intelligence (AI) algorithm that automates this process.

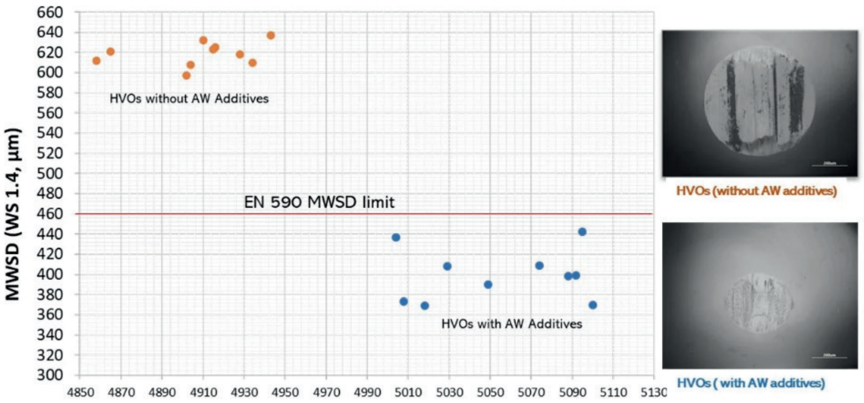


Figure 2 HFRR lubricity of HVOs with and without anti-wear additives

HFRR 4.2 screens and control quality of next-gen renewable fuels to comply with EN 590 MWSD limit.

Global fuel quality monitoring programs reveal that the HFRR wear scar has values significantly lower than Worldwide Fuel Charter recommendation of 400 microns due to different additive chemistries and concentrations. This range of excellent to intermediate lubricity between 200 to 500 microns has wear scars that do not have well defined shape and boundary due to the underlying tribofilm formation and wear mechanism. Visual observation is widely accepted method to detect and quantify the wear on the HFRR specimens. As a result, precision in measurement can be expected to be poor, something that is well recognized within this community. This can increase the error and test variability as seen in Figure 3a.

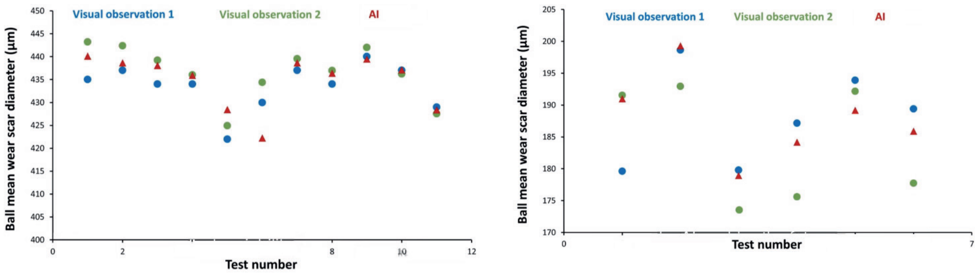


Figure 3a Mean wear scar values of intermediate and excellent lubricity fuels measured manually by two operators as well as using AI automated algorithm.

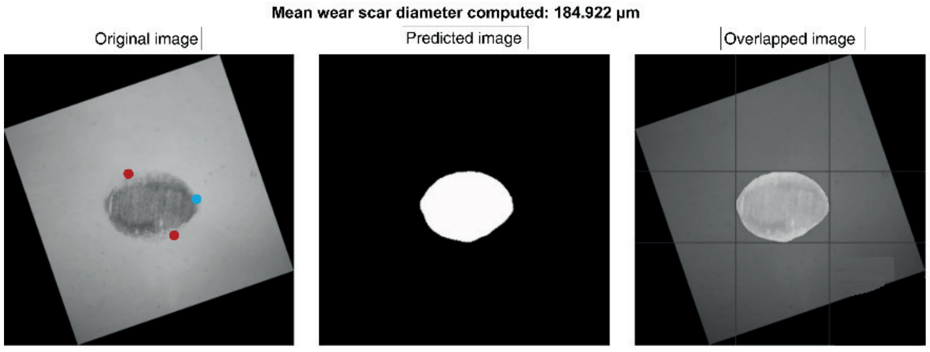


Figure 3b AI algorithm that automatically detect the edge of the scar and measures the mean wear scar diameter on the ball.

AI based algorithms with image segmentation techniques can consistently and precisely detect the edges of the scars and predict wear scar diameter eliminating operator variability in reporting data from fuels. ***Such AI tools will become indispensable for the fuel and lubricant industry to accurately quantify ultralow wear sustainable fuels of the future.***

Conventional test methods may not be adequate for electric vehicle lubricants

The automotive industry has undergone a revolutionary shift with the rise of electric vehicles (EVs) in the pursuit of sustainable transportation. EVs require specialized formulations for electric motors, gear systems, and bearings. The transition to electric mobility demands cutting-edge lubricants with enhanced thermal stability, conductivity, and anti-wear properties to address challenges like higher temperatures and increased power density. The industry is adapting to these needs to ensure optimal efficiency and durability in EVs especially balancing the lower viscosity lubricants with durable anti-wear additives.

Standard testing methods may fall short in accurately gauging the performance of lubricants in electric vehicles. In this study, we evaluated the anti-wear, extreme pressure and viscosity loss of two different EV fluids according to widely used ASTM and CEC test standards. These e-lubricants were tested on four ball tester, FBT 3.0 with KRL attachment (Figure 4)

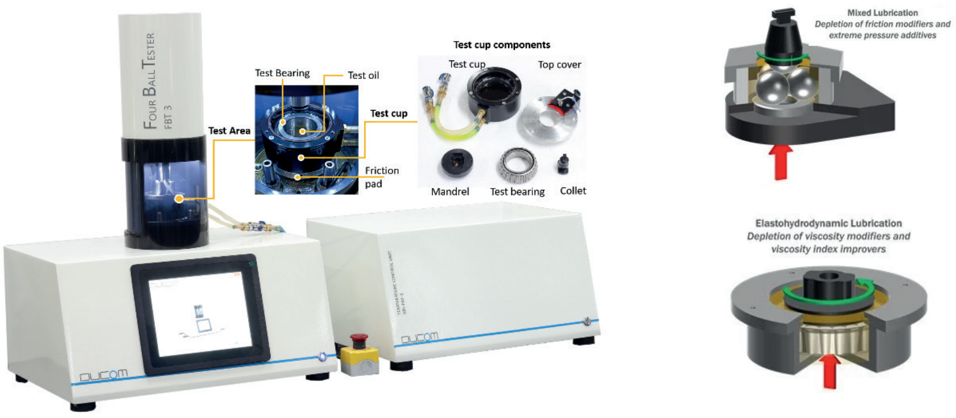


Figure 4. FBT 3.0 with KRL attachment and temperature control unit. Insert shows the four ball and KRL test bearing geometries

Two different EV fluids having low and high viscosity were selected for viscosity loss study Table 1.

Table 1. Chemical composition of low viscosity and high viscosity fluids.

	Unit	Low viscosity	High viscosity
Kinematic Viscosity (100 °C)	cSt	7.5	9.0
Density	kg/m^3	950	950
Flash Point	°C	200	200

According to the CEC L-45-99 standard, the fluid under test must be sheared for 20 hours under high load (5000 N) and high speed (1475 rpm) conditions. The temperature was kept at 60±1 °C. The same fluids were sheared under the same test condition for an extended duration of 200 hours. After each test, the viscosity of the fluid was measured and compared to the viscosity of the non-sheared fluid to calculate the viscosity loss.

A unique feature of the KRL attachment is the friction measurement capabilities. Friction measurement is not a requirement of the CEC standard. However, friction coefficient can be an insightful parameter along with viscosity loss. Figure 5 shows the friction coefficient behaviour of the fluids sheared for 20 and 200 hours respectively. In both cases, the high viscosity fluid showed higher friction compared to the low viscosity fluid.

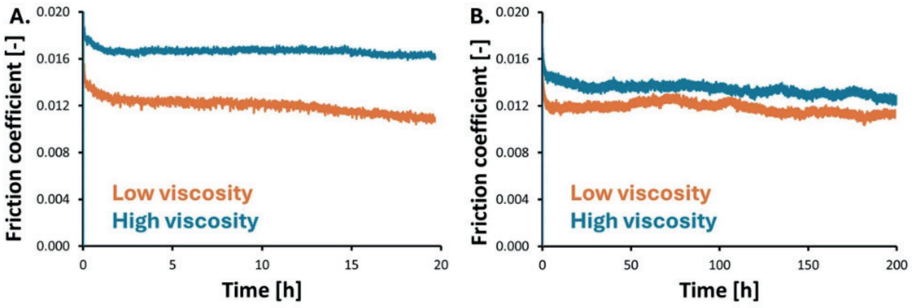


Figure 5. Inline friction measurement during KRL shear test for low and high viscosity fluids.

The permanent viscosity loss (see Figure 6) of the low viscosity fluid was 4% and 6.17% for 20 hour and 200 hours tests, respectively. The viscosity loss of the high viscosity fluid was 3.67% and 5.65% for 20 hour and 200 hours tests, respectively. The viscosity loss for both fluids was 1.5 times higher after shearing for 200 hours compared to the standard 20 hours test. ***Longer duration KRL tests of 200h better represent the actual field observed degradation of viscosity modifiers compared to the conventional 20h test.***

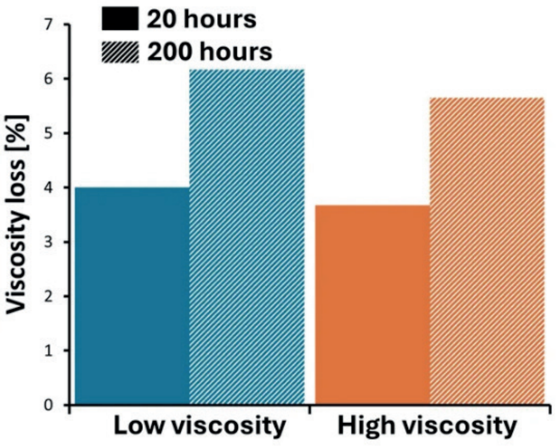


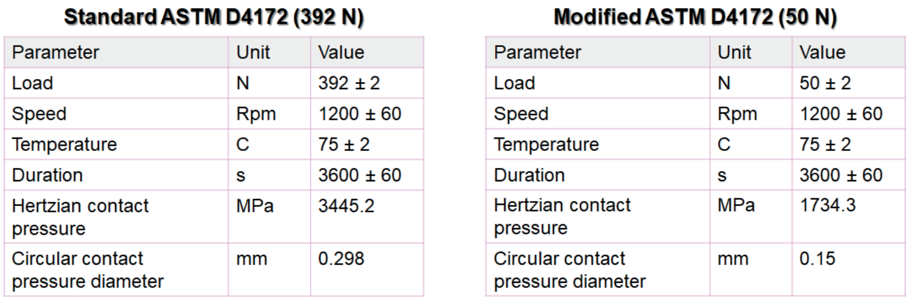
Figure 6. Viscosity loss for low and high viscosity lubricants after 20h and 200h testing.

Two different low viscosity EV fluids having different anti-wear additive concentrations were tested in four ball tester (FBT 3.0) (Table 2)

Table 2. Properties of low and high anti-wear EV fluids

	Unit	low anti-wear	High anti-wear
Kinematic viscosity (100 deg C)	cSt	4	4
Density	kg/m^3	950	950
Flash point	deg C	200	200

According to the ASTM D4172 standard, the fluid under test must be tested at 392 N for 1 hour at 75 °C at a speed of 1200 rpm. After each test, the wear scar diameters were accurately measured using automated AI tools. A lower test load of 50 N was used as well to evaluate the anti-wear properties of these low viscosity e-lubricants.



Standard ASTM D4172 (392 N)

Parameter	Unit	Value
Load	N	392 ± 2
Speed	Rpm	1200 ± 60
Temperature	C	75 ± 2
Duration	s	3600 ± 60
Hertzian contact pressure	MPa	3445.2
Circular contact pressure diameter	mm	0.298

Modified ASTM D4172 (50 N)

Parameter	Unit	Value
Load	N	50 ± 2
Speed	Rpm	1200 ± 60
Temperature	C	75 ± 2
Duration	s	3600 ± 60
Hertzian contact pressure	MPa	1734.3
Circular contact pressure diameter	mm	0.15

Figure 7. Conventional and modified ASTM D4172 anti-wear test protocols

Using the standard test of load of 392 N, the difference between the mean wear scar diamaters of low and high anti-wear oils was only 30 microns which was within the precision of the test method. Under the modified test at a load of 50 N, the difference between the same oils increased 160 microns (Figure 8). ***Thus the next generation of low viscosity EV fluids with antiwear additives require non-conventional procedures to screen and develop best chemistries.***

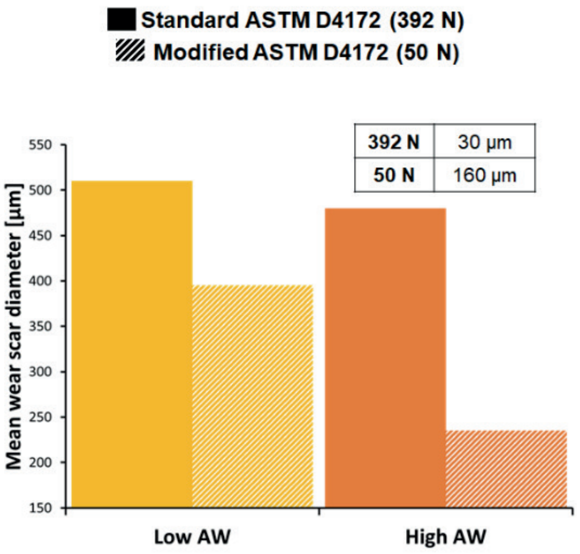


Figure 8. Anti-wear performance using conventional and modified ASTM D4172 standard

Our study reaffirms that lubricant performance cannot be solely assessed by traditional test standards and metrics, and there is a need for a paradigm shift in lubricant testing and formulation for electric vehicles. The Four Ball Tester (FBT-3), among other instruments, offers a paradigm shift to users develop new solutions for the challenges that electric vehicle fluids pose to the lubricants community.

A new line of Electrical Lubricant Test Rigs (ELTs) that can address all the critical test parameters required for qualifying fluids and greases used in lubricating electric drive train components are under development. These include electrified four ball tester, modular traction tribometer, high speed e-fluids test rig for investigating effect of electric fields and high speeds on friction, wear and durability of e-fluids.

Figure 9. Modular traction tribometer compatible with electrified module

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