

Diesel Fuel Lubricity Comparisons with HFRR and Scuffing Load Ball-on-Cylinder Lubricity Evaluator Methods

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ABSTRACT

Diesel fuel requires sufficient lubricity to prevent excessive wear in fuel injection equipment. The processes for removing sulfur from diesel fuel also eliminate compounds that are responsible for its lubricating properties. This phenomenon is counterbalanced by employing lubricity additives to restore fuel lubricity to an acceptable level.

The aim of this study was to compare the two different laboratory methods for testing lubricity. The two methods were the EN 590 standard method high frequency reciprocating rig (HFRR) and a less utilized method scuffing load ball-on-cylinder lubricity evaluator (SLBOCLE). Two different commercial lubricity additives were used. In addition, rapeseed methyl ester (RME) was used for lubricity purposes in the same way as the additives. To study the possible effect of the base fuel, the tests were performed with fossil diesel fuel, paraffinic diesel (Hydrotreated vegetable oil, HVO), and a blend of these.

The best HFRR - SLBOCLE correlation was found with RME used as a lubricity additive, but the results were still conflicting concerning the approval limits. With the commercial lubricity additives, the best correlation was achieved with paraffinic diesel base fuel and acidic type of lubricity additive. Ester based lubricity additives gave seemingly random SLBOCLE results while the acid based lubricity additive produced slightly more coherent results. The correlation was poor with all different additives when the base fuel was 100 % fossil.

The results indicate that the correlation between HFRR and SLBOCLE is generally poor. While HFRR showed improved lubricity trend by increasing dosing level of the additive, SLBOCLE did not. The reason for this may be that the methods are measuring two different types of phenomena - wear and seizure. SLBOCLE also seems to rule out fuels which have shown good behavior in the market, if the suggested limit is applied. The writers feel that the repeatability and reproducibility of SLBOCLE method would need substantial improvement.

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INTRODUCTION

Lubricity is a crucial quality parameter for diesel fuels. It is only the fuel that provides lubrication for the fuel injection equipment in most light and heavy duty diesel engine applications.

Therefore, this characteristic must remain at a satisfactory level. Otherwise excessive wear or even catastrophic failures may occur. As such, oil refiners aim to give consumers a product that in no circumstance jeopardize the fuel injection equipment of their vehicle.

Lack of lubricity first became an issue some 20 years ago, when new European legislation began demanding fuels with lower sulfur levels. This is achieved by a process called hydrotreating. In addition to removing sulfur compounds from the fuel, it also eliminates other polar oxygen and nitrogen containing components which are found in trace amounts in diesel fuel. These polar components are mainly responsible for

the anti-wear properties of diesel fuel. In some regions, Sweden for example, a rapid reduction in fuel sulfur content led to problems in the field, causing severe damage to vehicles using the new sulfur-free fuels.

Since then, a considerable amount of effort has been put into developing a quick and reliable test method to determine the lubricating qualities of a given fuel. The EN 590 standard requires a test method called HFRR (High Frequency Reciprocating Rig). However, other methods exist, and in this study SLBOCLE (Scuffing Load Ball-On-Cylinder Lubricity Evaluator) was utilized as well.

Since these two laboratory methods are used to measure more or less the same variable, it is important to know how the methods correlate with each other. A comprehensive study of

the two methods was carried out in the late 1990s, and the results are reported by Manuch Nikanjam of the Chevron Products Company [1].

Earlier, an ISO (International Organization for Standardization) round robin program [2] had identified a 450 μm maximum limit for HFRR and a 3100 g minimum limit for SLBOCLE. Since their results were not consistent in a way that an acceptable HFRR result would also give an acceptable SLBOCLE result and vice versa, one has to conclude that the methods do not correlate well with each other.

Furthermore, if one had total confidence in one method, the other method could be ruled out as inaccurate. Nikanjam [1] is prone to trusting SLBOCLE more, based on good field experience of low aromatics fuels in California since 1993. In contrast, HFRR has been the prevailing test method of the since it was introduced to EN 590 standard in the mid 1990's, and no major problems in the field have arisen either. However, there is some indication that HFRR may underestimate lubricity properties of a fuel and lead to excessive use of additives [3]. Therefore, fuels that exceed the HFRR limit slightly may still provide adequate field performance. Nonetheless, HFRR has been successfully utilized in the recent years, and it remains the standard method for fuel lubricity.

The industry understanding of diesel fuel lubricity has greatly improved over the past 20 years, and due to widespread use of lubricity additives it is no longer a pressing issue. However, as common rail systems have gained popularity in automotive use since the early 2000s, researching lubricity and its effects in modern fuel injection equipment have become topical again. Also, the importance of testing new renewable fuels, both in the laboratory and on a test bench, is on the rise.

METHODS

High Frequency Reciprocating Rig - HFRR

The standard test method for diesel fuel lubricity in Europe is the High Frequency Reciprocating Rig, or HFRR. The method is described in the standards ISO 12156 [4] and ASTM D 6079 [5]. These two standards differ in the way of reference measurements, repeatability and reproducibility and in that the ASTM method uses the direct measurement result, whereas the ISO method uses a wear scar diameter corrected with a humidity factor. For this paper, the ISO method was used for all measurements.

The repeatability of the ISO 12156 method for HFRR is 63 μm and the reproducibility 102 μm [4].

Scuffing Load Ball-On-Cylinder Lubricity Evaluator - SLBOCLE

The Scuffing Load Ball-On-Cylinder Lubricity Evaluator (SLBOCLE) is another piece of equipment used for testing diesel fuel lubricity. The method for running the test is outlined

in the ASTM D 6078 standard [6]. Where the HFRR produces sliding wear on the test specimen, the SLBOCLE produces scuffing wear.

The repeatability of the ASTM D 6078 for SLBOCLE is 900 g and the reproducibility 1500 g [6].

A comparison of the specifications of the two used methods is presented in Table 1.

Table 1. Lubricity test method comparison.

Test Method	High Frequency Reciprocating Rig	Scuffing Load Ball-On-Cylinder Evaluator
Abbreviation	HFRR	SLBOCLE
Result	Wear Scar Diameter [μm]	Load [g]
Approval Limit	$\leq 460 \mu\text{m}$ *	$\geq 3500 \text{ g}$ **
Repeatability	63 μm ***	900 g ****
Reproducibility	102 μm ***	1500 g ****
* Defined in EN 590:2013		
** Proposed in CEN/TS 15940:2012, Annex A		
*** Method ISO 12156		
**** Method ASTM D 6078		

Test fuels

Three base fuels were used in this study. The fuels were 100 % fossil winter grade diesel, 100 % HVO, and a blend of 70 % fossil diesel and 30 % of HVO. The test fuel properties are presented in Table 2. More information on HVO can be found in SAE 2008-01-2500 [7].

The winter grade fossil diesel fulfils the severe winter requirements of the EN 590 standard [8]. In cold climates, properties such as density and viscosity are allowed lower values for better cold performance, namely lower cloud point and CFPP.

The HVO type fuel, on the other hand, complies with the paraffinic diesel fuel technical specification (CEN/TS 15940:2012) Class A without FAME [9]. Different requirements are a result of HVO being a purely paraffinic fuel, and paraffins have lower density compared with other diesel fuel hydrocarbon classes with the same number of carbon atoms [10]. For this reason, paraffinic fuels such as HVO are usually blended with regular diesel fuels. The blend then has sufficient density to meet the EN 590 standard and it still holds the good properties of the HVO fuel, such as high cetane number. The 70 % fossil + 30 % HVO blend is an example of such a fuel blend in this study.

Table 2. Base fuel properties

Property	Unit	Fossil diesel	HVO
Density 15°C	kg/m ³	818,2	778,9
Cloud Point	°C	-29	-19
Cold Filter Plugging Point	°C	-29	-19
Viscosity 40°C	mm ² /s	1,843	2,901
Sulfur Content	mg/kg	8,5	<1
Flash Point	°C	60	83
Cetane Number	-	49,1*	79,6
Monoaromatic Content	wt-%	16,5	<0,2
Diaromatic Content	wt-%	1,5	<0,1
Tri+ Aromatic Content	wt-%	<0,1	<0,10
Polyaromatic Content	wt-%	1,5	<0,1
Total Aromatic Content	wt-%	18	<0,2
HFRR	µm	653**	580**
Initial Boiling Point	°C	167	193
5% (V/V) recovered	°C	189	237
10% (V/V) recovered	°C	195	253
20% (V/V) recovered	°C	204	267
30% (V/V) recovered	°C	212	274
40% (V/V) recovered	°C	222	279
50% (V/V) recovered	°C	230	282
60% (V/V) recovered	°C	240	284
70% (V/V) recovered	°C	252	287
80% (V/V) recovered	°C	267	290
90% (V/V) recovered	°C	288	292
95% (V/V) recovered	°C	305	294
Final Boiling Point	°C	320	299
% (V/V) recovered at 180°C	% (V/V)	1,5	<0,1
% (V/V) recovered at 250°C	% (V/V)	68,3	9
* Requires cetane improver to meet EN590 cetane requirement $\geq 51,0$			
** HFRR without any lubricity additives			

Lubricity additives used

Typical chemical structure for a lubricity additive consists of a polar functional group and an oleophilic part [11] [12]. Three types of functional groups are commonly in use: carboxylic acid, carboxylic acid ester and carboxylic acid amide. These can be called acid, ester and amide for short. The functional group makes a compound polar, which makes it surface active and a good boundary lubricant. Correspondingly oleophilic part makes the additive fuel soluble.

In this study, two chemically different additives were used. The additives will be called acid and ester based on their functional groups, instead of their trade names. Furthermore, RME was used as an additive in a sense, as it was added to the base fuels in minor concentrations. This was done because fatty acid methyl ester (FAME) type fuels are well known for improving lubricity [13].

Treat rates

The treat rate for both commercial additives was investigated by performing HFRR tests and finding concentrations that produced good, borderline and poor lubricity. These doses are called high, medium and low doses, respectively. Borderline lubricity was termed to mean a result of 460 µm, which is the limit defined in the EN 590 standard. Moreover, good and poor lubricities were thought to mean a result that significantly differs from the standard limit, less than 400 µm and over 500 µm to give an example. Still, as slight changes in the additive concentration can produce drastic changes in the wear scar diameter, and taking the repeatability of the procedure into account, these values were not taken as a definite guideline.

Overdosing with lubricity additives is an unnecessary cost. Thus, it is in the interest of refineries to research additives and dosing rates, as well as their impact on fuel injection equipment.

RME

Three different RME concentrations (volume) chosen were 0,5 %, 2 % and 7 %. The lowest concentration was designed to give an unacceptable result with HFRR, 2 % was an acceptable level and 7 % is the maximum allowed RME concentration within EN 590.

RESULTS AND DISCUSSION

In this chapter the results are presented and discussed with one lubricity additive at a time.

Ester additive

The HFRR response for all three base fuels with different treating rates using ester lubricity additive is presented in [Figure 1](#) and the SLBOCLE response with same fuels and treat rates is presented in [Figure 2](#).

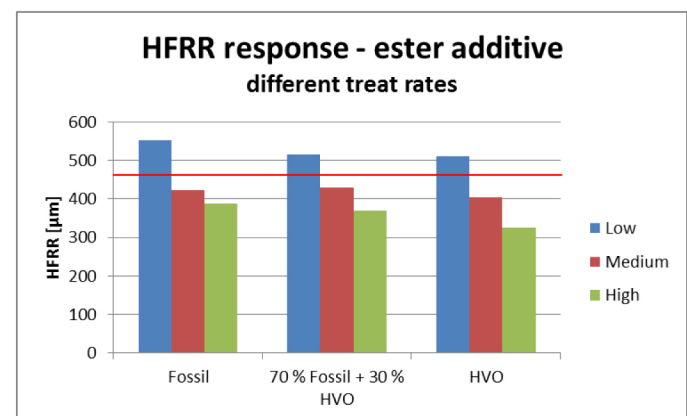


Figure 1. HFRR response with all test fuels and varied ester lubricity additive treat rates. The red line is the HFRR maximum limit of 460 µm defined in EN 590 [8].