ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1165389

DISCUSSION ON THE METHODOLOGY OF THE LUBRICITY DETERMINATION OF DIESEL FUELS, CONTAINING NON PETROLEUM COMPONENTS

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Abstract

The paper describes the usability of current test methods employed in fuels for CI engines testing for fuels containing non-petroleum components. The paper describes test results that justify the necessity for test method modification and for establishing new criteria for assessment of such fuels usability. The analysis covered typical courses of friction coefficient and electrical contact potential as film thickness during test. During standard test the wear stages were isolated, and then referenced to actual operation of friction pair in fuel supply system of diesel engine. Test results show that methodology used up to date is not useful. The restriction to standard corrected wear scar diameter (WS 1.4) is not enough for proper interpretation of course and effects of model wear. Moreover, it is impossible to reference to actual operation conditions, which is inconsistent with tribological testing rules. Such rules mean that testing conditions reflect the actual ones as much as possible.

Characteristics of test technique using HFRR, discussion on test method usability for testing the modified fuels, lubricity change vs. the increase of concentration of hydrocarbons typical for biohydrocarbons from Fischer-Tropsch process, comparison of changes of friction coefficient and lubrication film thickness for samples are presented in the paper.

Keywords: *CI engine, CI fuels, non-petroleum fuel components, fuel tribochemical characteristics*

1. Introduction

Petroleum products, incl. also the fuels, belong to group of the ones having extended system of their characteristics assessment. Within the space of years, basing on developing theoretical knowledge and progressing experience, especially in the extent of operation, they created the assessment system that takes into consideration several problems:

- technological – regarding production repeatability assurance at required quality level,
- operational – regarding assurance of optimal equipment usage conditions in which the specific petroleum product is employed,
- ecological – regarding as low as possible effect on environment.

The appropriate characteristics together with specifically selected test techniques have been designated for each of above-mentioned groups. The techniques were developed according to current experience, strictly connected with characteristics of the product and its usage.

The issues of lubricity in relation to usefulness of this parameter to assess the lubricant usefulness (in this case – the fuel lubricating precision pairs of fuel supply system of diesel engine). Lubricity is determined at laboratory. The lubricity determination technique has been developed in such manner as to reproduce operation condition of actual frictional joint.

2. Characteristics of test technique using HFRR

Lubricity of fuels such as fuel oil is determined with test methods described in standard documents (e. g. EN ISO 12156-1 [1], ASTM D6079-11 [2], ASTM D7688-11 [3]), using HFRR, illustrated schematically in Fig. 1.

a) b)

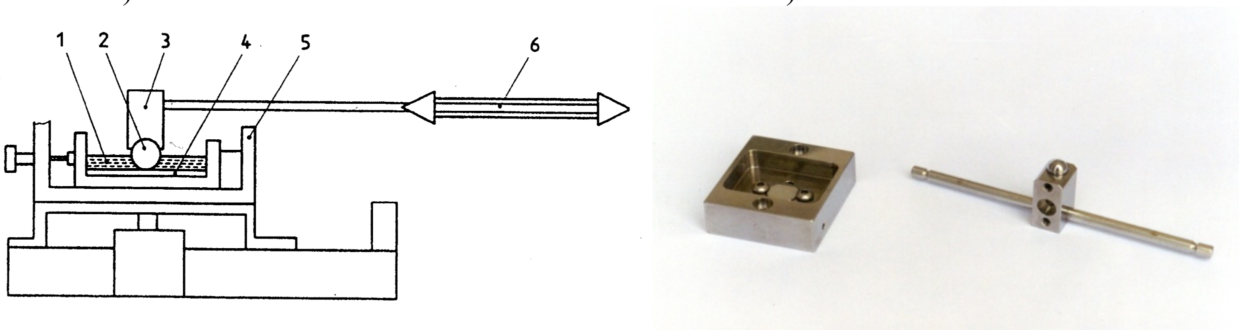


Fig. 1. HFRR test unit: a) scheme: 1 – lubricant, 2 – upper specimen (ball), 3 – upper specimen holder, 4 – lower specimen (plate), 5 – lower specimen holder, 6 – fretting flexure lock, b) specimens: left: lower holder with plate, right: upper holder with ball

The friction joint (pair) operates under repeating movement at low sliding frequency, so it simulates conditions in friction pair of CI engine fuel delivery system (in fuel injection pump or in injectors). The ball is pushed against fixed disc. The ball oscillates at small amplitude using solenoid oscillator (it's possible to adjust oscillation amplitude and frequency).

Specific equipment enables to measure both the friction force and electrical contact potential (ECP) between ball and disc. The ECP enables lubricating film monitoring. Mating elements made of specific materials are used as standard, but it is possible to use other ones to be closer to actual conditions. The mating elements are submerged in lubricant during testing. It is possible to heat the lower specimen as well as to change the humidity in measurement chamber.

Standard documents e.g. [1-3] describe testing using strictly specified materials of mating elements, and performed at explicitly definite conditions (load, oscillation frequency, advance length, time, humidity and temperature).

Furthermore, it is possible to perform non-standard testing. It is possible then to perform comparative analysis of the effect of external factors on lubricity describing parameters.

3. Discussion on test method usability for testing the modified fuels

Most physical and chemical parameters describing utility fluids properties are treated universally, i.e. they are used to make an evaluation of many products similar in type and purpose. Therefore, it is assumed significant similarity regarding physical and chemical phenomena happening during test as well as relationship between laboratory test results and actual operation condition of utility fluid in the appliance.

However, not all parameters can be treated in the same way. According to author of the paper, the lubricity is such parameter.

Standard test methods [1-3] have been developed for fuel oils of petroleum origin. Friction pair of test rig simulates operation of precision pairs of injection system, where petroleum fuel oil is used also as lubricant. Experience shows that test results from simulating rig relates to actual operation conditions of precision pairs of injection system, so there are no problems regarding interpretation. Unfortunately, such problems appear in case of modified fuels, such as biofuel or biocomponent, that is the mean of partially or fully different chemical structure.

As for the lubricity, there is common confidence that introduction of biocomponents such as FAME into fuel oil considerably improves lubricity. It is confirmed by test results using HFRR. Increase of biocomponent concentration resulted in significant decrease of wear scar for friction pair of test rig. Such increase obtained in laboratory has not been confirmed by real operation. More frequent cases of seizing of precision pairs of CI engines injection system. There are two most probable reasons for damage fatigue:

- appearing of ground material from e.g. microdeposits of metal catalysts used in esterification process,
- insufficient lubricity.

Deposit generation at test conditions is not possible, so the first item could be excluded for model pair. The prevailing conditions are too mild to cause deposits precipitation from lubricant (e.g. process residues – in case of FAME), and then to cover matching elements or to appear in lubricant as debris. Such difference is the first reason for doubts regarding suitability of traditional technique.

Not every fuel includes components able to create such microdeposits. For example, biohydrocarbons, unlike FAME, are free of catalyst residues. Therefore, we can assume that primary condition affecting both the scope and intensity of wear at test conditions is lubricity.

In case of „traditional" fuel oils with in spec, HFRR corrected wear scar diameter there are no operational problems. However, it is not so plain in case of fuels containing components of new generation (e.g. biohydrocarbons). The laboratory test results are not explicit. In case of traditional fuel, increase of lubricity improver content causes actual improvement of this parameter. Components of different chemical character, introduced into the traditional fuel, disturb this relationship. This is connected with different nature of tribochemical reactions taking place in presence of chemically different biocomponents or biohydrocarbons [4]. Reaction start needs proper activation energy, what in case of equal starting circumstances, but different reagents, leads to various chemical reactions. Additional factor changing activation energy could be the presence of residues of catalysts used in biocomponents production [5, 6].

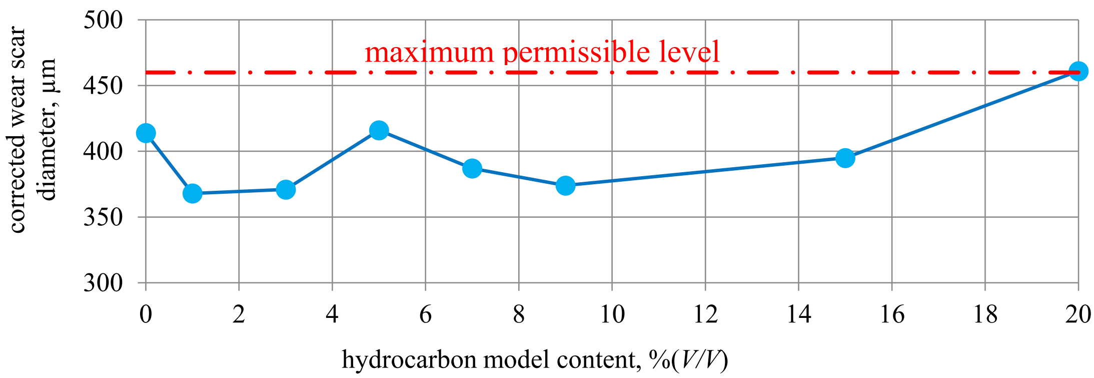


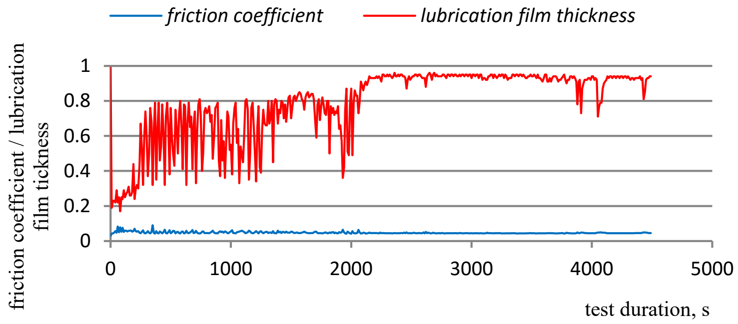
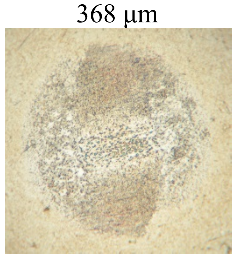
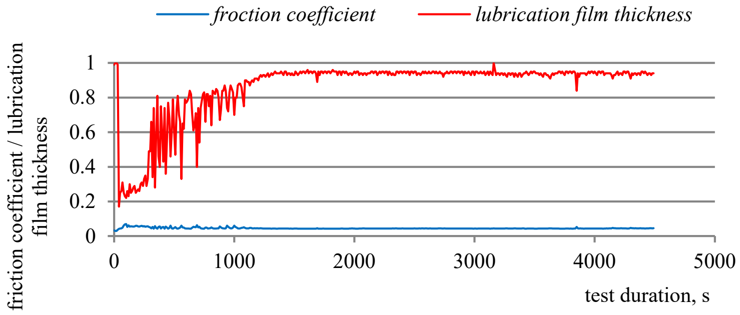
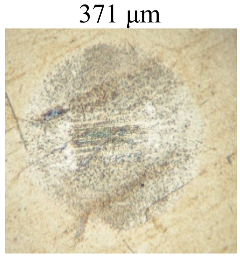
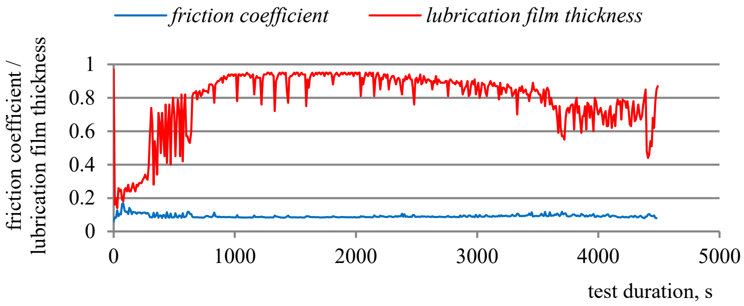
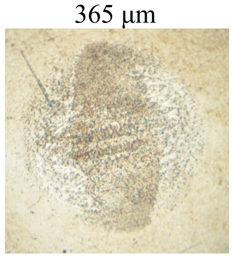
Fig. 2. Lubricity change vs. the increase of concentration of hydrocarbons typical for biohydrocarbons from Fischer-Tropsch process

Figure 2 shows lubricity change vs. the increase of concentration of hydrocarbons typical for biohydrocarbons from Fischer-Tropsch process. It is different from for „traditional" fuel oil, which is of nature close to the line one.

There were irregularities for low concentration of biohydrocarbon model. Precise analysis covered 3 points with similar corrected wear scar diameter, i.e. the ones corresponding to biohydrocarbon model of 1, 3, and 9% (*V/V*). The difference between extreme values of scar diameter is 1.6%, so, in case of use exclusively the standard method of results evaluation, it can be assumed that lubricity is almost the same in all cases. Using non-standard capabilities of the method, the results can be explained little bit differently. The Tab. 1 shows charts of friction coefficient, and ECP describing film thickness. Furthermore, the images of wear scar are shown. Comparison of these charts is shown in Fig. 3.

According to shown above, standard procedure for lubricity, assessment is implausible. Despite different courses of test parameters, the final results, i.e. wear scar diameters, are comparable. Because of that, the analysis of film thickness was performed. The Fig. 4 shows the test cycle divided into three phases (stages). Relevant increase of wear scar diameter was designated to every of such phase.

Tab. 1. Change of friction coefficient and lubricating film, and images of wear scar on test ball for samples of identical corrected wear scar diameter WS 1.4

<table>
<tr><th>Model conc., %(V/V)</th><th>Change of friction coefficient and film thickness during measurement run</th><th>WS1.4 / Image of wear scar on the ball</th></tr>
<tr><td>1</td><td>
</td><td>368 µm
</td></tr>
<tr><td>3</td><td>
</td><td>371 µm
</td></tr>
<tr><td>9</td><td>
</td><td>365 µm
</td></tr>
</table>

First phase (stage), connected with junction running in, has the same nature (film thickness changes amplitude, increase intensity and duration) for majority of fuels under testing. At this time, in practically metallic contact, the intense wear of working elements takes place. As an example, the corrected wear scar diameter in performed test reaches the value of 324 µm (83% of total wear scar diameter). The second phase (stage) can be described as stabilization of film thickness. This stage covers continuous film creation and breaking, shown as large changes of lubricating film. There is increase of wear scar 40 µm (10% of total wear scar diameter). The third phase (stage) means the film stabilization. It covers increase of wear scar 28 µm (7% of total wear scar diameter). Because the first phase (stage) is equal for majority of typical testing, the lubricity of fuel under investigation is described by courses (runs) in the second and third one. This is confirmed by results of 3 runs performed for the same junction (without change of working elements) (Fig. 5).

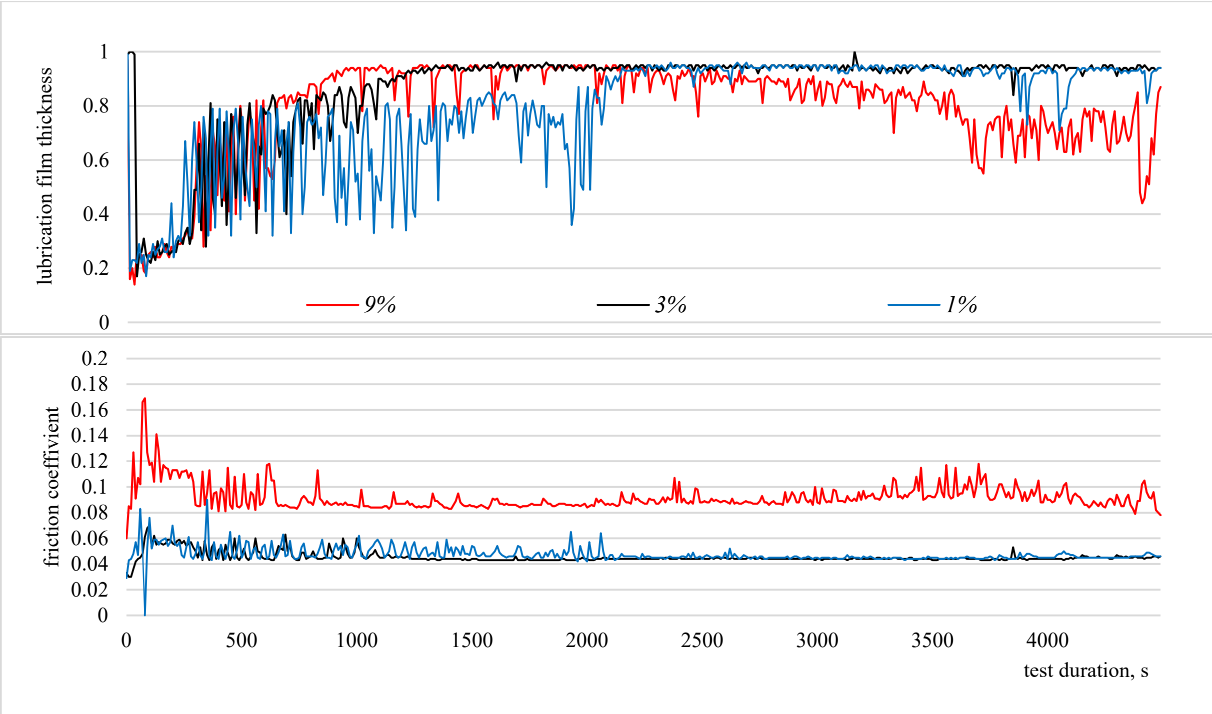


Fig. 3. Comparison of changes of friction coefficient and lubrication film thickness for samples of identical corrected wear scar diameter WS 1.4

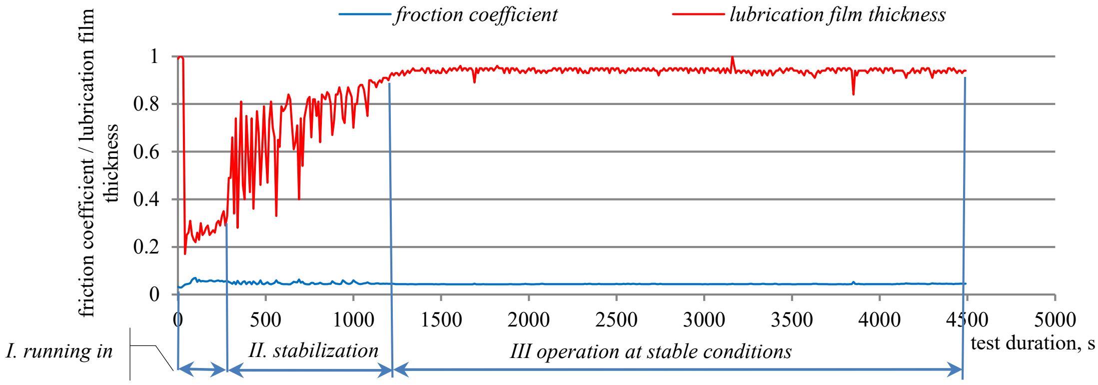


Fig. 4. Phases of test cycle at HFRR

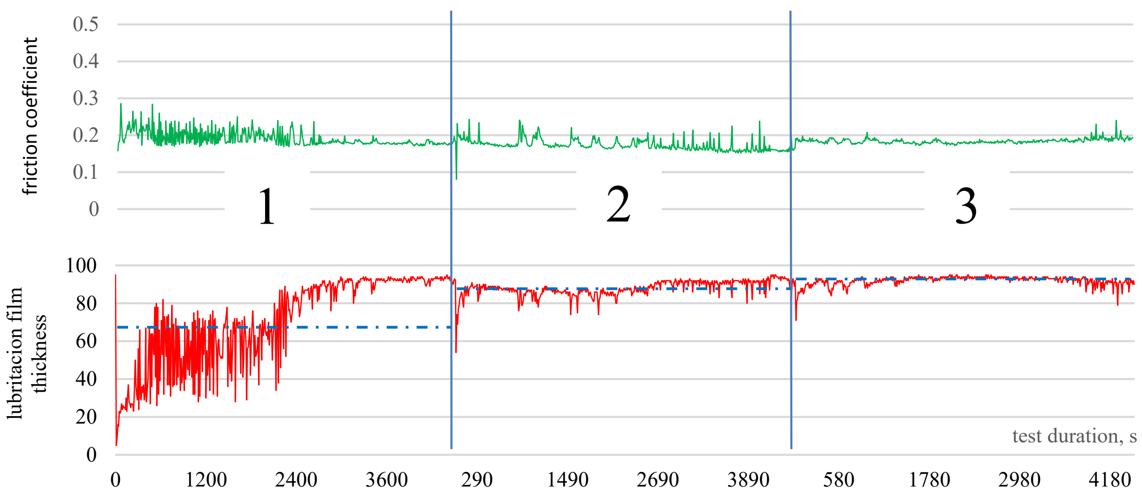


Fig. 5. Runs repeated for the same set of test elements of tribological system (dotted lines correspond to mean values during individual runs)

Significant elements of the first run are running in and film stabilization. Actually, half of the run takes place at unstabilized conditions. There are such phases (stages) at run 2nd and 3rd, so the increase of wear scar diameter is significantly lower (Tab. le 2).

Tab. 2. Test parameters with repeated runs

Parameter	1st run	2nd run	3rd run
corrected wear scar diameter at the end of run(s), µm	383	481	524
increase of corrected wear scar diameter for the run, µm	+383	+98	+43
mean value of film thickness coefficient	71.25	87.95	91.93
mean value of friction coefficient	0.191	0.173	0.184

The highest increase of wear scar diameter is seen at the first two phases (stages) of operation of friction joint in presence of lubricant – running in and lubricating film stabilization. Furthermore, it was observed that change of film thickness and friction coefficient at the first phase (stage) is eventually the same despite lubricant used. At the same time, it is not possible to designate these stages to any operation conditions. Basing on charts (Fig. 4 and 5), it can be assumed that wear at first phase (stage) is the highest and is about 10% of total value. The second phase (stage) covers the next 10 – 20%. This value, in that case, already depends on lubricant used, but there is no potential equivalent at actual operation. It is shown plainly in Fig. 5, where, in case of run II and III, this phase (stage) is very short – eventually omittable – does not repeat.

Such considerations lead to conclusion that operation of actual tribological joint (pair) (working elements and lubricant) could be copied in testing rig at cycle (stage) III. According to both changes of film thickness and friction coefficient, we can observe the film stability, i.e. the operation under fluid friction, and its possible breaking, which is typical for semi-fluid friction, where the wear is higher.

Because the standard methodology does not use the analysis of friction parameters' charts, this phase (stage) has the lowest importance for interpretation of lubricant quality. There are no its assessment criteria that were not required in case of repeatably testing of petroleum diesel fuels. In case of non-petroleum components use, standard lubricity testing is not reliable. Therefore, the methodology needs to be modified. In order to establish the new criteria for diesel fuels testing they have to perform further validation testing.

4. Summary

1. The HFRR test method, used up to date, for determination the lubricity of fuels for CI engines is not fully applicable for fuels containing non-petroleum components.
2. The standard test method assessment does not use the possibility for evaluating the course of friction coefficient, film thickness, and wear scar pictures that are very different though very close values of corrected wear scar diameter WS 1.4.
3. The wear scar is mostly affected during standard by testing phases (stages) that cannot be designated to any conditions of operation of actual fuel supply system (injection pump, injectors).
4. The non-petroleum components have other tribochemical characteristics, so they significantly change the operation of model tribological joints (e.g. HFRR). Therefore, it is necessary to modify the methodology of assessment of CI engines fuels with such components.

References

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by the High-Frequency Reciprocating Rig (HFRR).

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