ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.2786

IMPACT OF THE ADDITIVES USED IN MINERAL JET FUELS ON THE LUBRICATING PROPERTIES OF SYNTHETIC FUELS FOR TURBINE AIRCRAFT ENGINES

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Abstract

Hydrocarbon containing synthetic fuels represent a promising alternative fuels. Despite different chemical compositions, their properties should be similar to properties of mineral fuels, as they are designed for the same drive units. The basic parameter related to the protection of the adequate service life of the power supply devices, including precision pairs, is lubricity. Lubricity depends on a number of factors, including these related to the chemical composition of fuel components and operating additives introduced into fuels in order to modify their properties. The preliminary results of research on the effect of additives: lubricating, anti-corrosion and anti-electrostatic once, on the lubricating properties of a synthetic fuel are shown in the paper. It was observed that there are relations between the content of additives and the dynamics of film formation. It is significant that this does not apply only to the lubricating additive, but also the additive, which protects the correct electrostatic balance by providing sufficiently high electrical conductivity of the fuel. This may indicate that the formation of a lubricating film remains in relation to the intensity of energy transport from the lubricated surface to the molecules of lubricating additives inside the film. The results shown in the paper preliminary confirm the hypothesis, that synthetic components of fuels change the concentration of ordered molecular structures (which are present in mineral part of fuels and which can be responsible for energy transport inside the lubricating film), what resulted in worse fuel ability to create protective film, and anti-electrostatic additive improves lubricity of blends of synthetic and mineral components.

Keywords: *lubricity, fuels for turbine aircraft engines, synthetic components, additives*

1. Introduction

The lubricity of fuels for turbine aviation engines is usually determine by the results of BOCLE test. This test simulates the process of protective film formation in one part of fuel pomp: rotating swash plate and piston. In case the fuel is mineral Jet, the experience enables ensure proper lubrication of fuel pomp in aircrafts engines when the results of BOCLE test meet the standard requirements. In this case, the BOCLE test is enough.

The idea to introduce biofuels to aviation requires verification of standard tests, including lubricity one [14]. The mechanism of lubrication by new kinds of jet fuels should be understood as it is possible [15].

Previous concepts of the mechanism of lubricating film formation under boundary conditions can be come down to interaction between additive molecules and surface of machine element being lubricated [1, 8, 10]. Above-mentioned mechanisms have been developed for many decades and have been widely described in many publications regarding tribochemistry. This mechanism does not explain many experimental data, including the influence of base fuel or oil (without additives) on the ability of lubricating additives to form lubricating film.

To obtain the appropriate lubricating properties of agents, which in the devices play i.e. the role of lubricants (fuels, lubricating oils), different kinds of lubricating additives, are introduced into them. They are considered to reduce the wear of lubricating elements of machines and decrease the frictional drag. Lubricated machine elements are subject to various forces (pressure force, rubbing speed). The additives that were experimentally selected to various ranges of forces differ in the chemical structure. Lubricating additives used to fuels, mainly to diesel fuel and fuel to turbine aircraft engines; belong to organic acids or their derivatives [17].

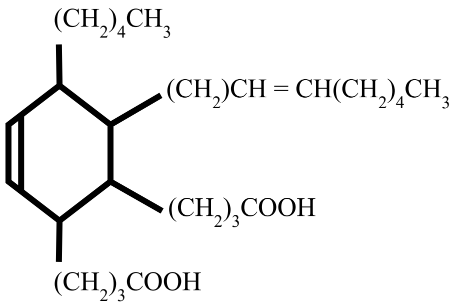
Chemical structure of the operating additives used to fuels of turbine aircraft engines.

a) Static Dissipator Additive (SDA):

C/H/O/S polimer + Polyamine + R-$S0_3H$ stabilizer,

b) Corrosion Inhibitor and Lubricity Improvers (CI/LI):

C_{17} COOH – dimer:



The mechanism of functioning the lubricating additives, including fuel additives: physical adsorption on the lubricated surface.

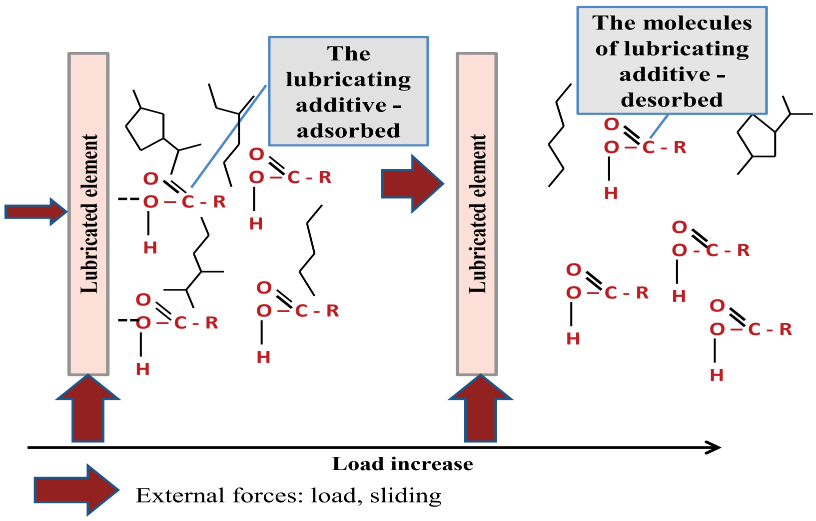


Fig. 1. Adsorption mechanism of lubricity improvers functioning at AW zone [1, 10]

Influences between the surface of the lubricated element and lubricating additives used in fuels – physical adsorption, can lead to the idea, that protective film is created by monomolecular layer or by a few molecular layers of small thickness. As a result, a very thin lubricating film with a limited durability is obtained.

The fact that effectiveness of lubricating additives depends on the chemical structure of basic fuel is well known, but adsorption theory of lubricating film does not clarify the impact of basic fuel (without additives) on the lubricity of fuel and the efficiency of lubricating additives. The previous research conducted by authors of this paper has enabled formulation of the following hypothesis:

Fuels lubricity should be described as energy flow between the material of solid lubricated element and protective film created by fuel. Amount of flowing energy and the direction of energy flow depends on friction conditions (applied load, sliding velocity), the amount of fuel introduced into the friction zone and on fuels chemical composition, including additives. Previous research leads to conclusion, that the ordered molecular structures play important role in energy flow [2, 3, 6, 7]. Synthetic components of fuels [9], as well as SDA, change the ordered molecular structures, their chemical composition, and concentration; these leads to the change in energy flow during friction and as a consequence change the influence of lubricating additives on protective film formation and the wear of lubricated elements.

This hypothesis concerning new postulated mechanism of protective film formation by jet fuels was verified. The results of experimental verification of this hypothesis are presented below.

2. Test method

2.1. Test materials

The mineral Jet A-1 fuel without additives (JET), synthetic hydrocarbon bio component (HEFA), and mineral diesel fuel were chosen to tests. The selected physical and chemical properties, as well as the chemical composition of both fuels, were presented in Tab. 1.

Tab. 1. The properties of base fuels used in BOCLE and HFRR tests

Property	JET	HEFA	JET+HEFA (50:50)
Total acid number, mg KOH/g	0.001	0.001	0.001
Viscosity at -20ºC, mm^2/s	3.847	4.092	3.981
Aromatics content, % (V/V)	11.3	0.0	5.8
Olefins content, % (V/V)	0.8	0.6	0.6
Naphthalenes, % (V/V)	0.14	<0.08*	<0.08*
Conductivity (at 24ºC), pS/m	3	230	53
BOCLE wear scar diameter, mm	0.90	0.98	0.89
HFRR wear scar diameter, µm	770	803	757
HFRR average film, %	0.6	0.5	1.9
HFRR average coefficient of friction	1.1444	0.8105	0.5814
* below the precision of the method			

To the tested fuels, the following additives were introduced:

- Corrosion Inhibitor and Lubricity Improvers (CI/LI),
- Static Dissipator Additive (SDA).

The chemical structure of used additives is shown below. The following blends were prepared:

Tab. 2. Blends of base fuels and additives used in BOCLE and HFRR tests

JET	HEFA	Blend (50 % (V/V) JET + 50 % (V/V) HEFA)
JET + 6 mg/kg SDA	HEFA + 6 mg/kg SDA	Blend + 6 mg/kg SDA
JET + 20 mg/kg CI/LI	HEFA + 20 mg/kg CI/LI	Blend + 20 mg/kg CI/LI
JET + 6 mg/kg SDA + + 20 mg/kg CI/LI	HEFA + 6 mg/kg SDA + + 20 mg/kg CI/LI	Blend + 6 mg/kg SDA + + 20 mg/kg CI/LI

2.2. Tribological tests

The lubricity of turbine aircraft fuels is examined using a BOCLE test (Ball on Cylinder Lubricity Evaluator) [4, 16]. In this case, a frictional matching consists of the immovable ball, which is pressed axially to the external surface of the rotating ring (Fig. 2).

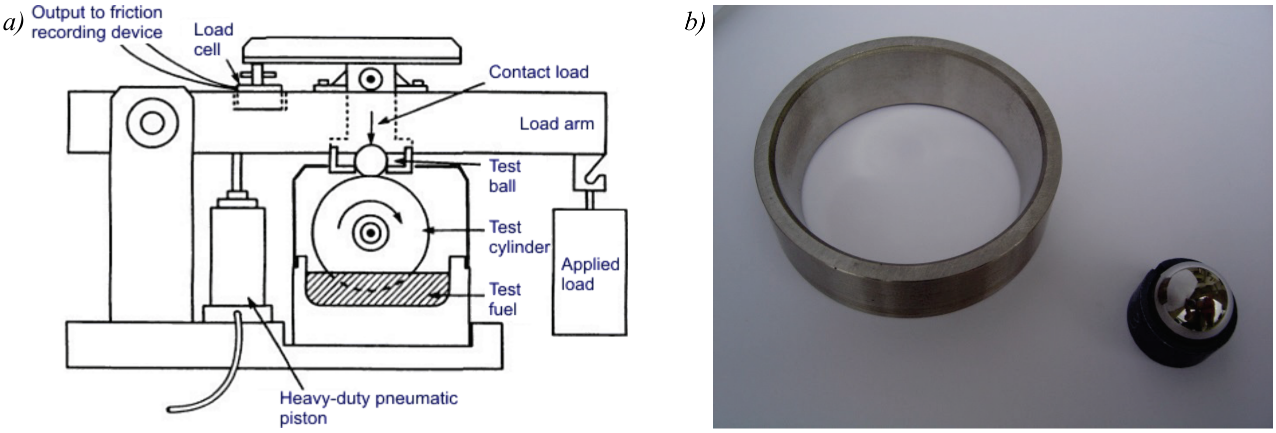


Fig. 2. BOCLE apparatus: a) scheme [11], b) elements of frictional matching

The movement of the ring partially immersed in the examined fuel contributes to the liquid being permanently brought to the point of contact of ball – ring. The trace of wear formed on the ball is measured.

The test conditions are as follows:

– rotating speed of cylinder: 240 rpm,
– load: 1,000 g,
– test duration: 30 min,
– fuels temperature: 25ºC.

BOCLE test does not simulate the lubrication of piston and cylinder of fuels piston pomp. Friction conditions in this part of fuels pomp make the mechanism of protective film formation different from this in BOCLE test. It was considered that new developed synthetic components of jet fuels can influence on the mechanism of lubrication of this part of fuels pomp and as the consequence can cause insufficient lubrication. The HFRR (High-Frequency Reciprocating Rig) test simulates the process of piston – cylinder lubrication much better than BOCLE test [5]. Its scheme is shown in Fig. 3.

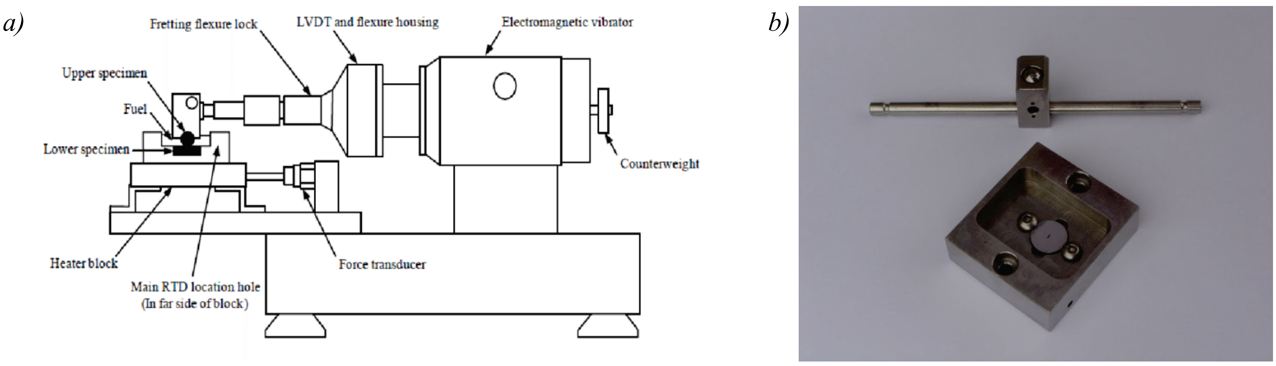


Fig. 3. HFRR apparatus: a) scheme [11], b) elements of frictional matching

Therefore, it simulates the conditions in the friction pair of injection apparatus of the fuel supply system of the compression-ignition engine (in injection pump or in injectors) [12]. To an immovable plate a ball is pressed, which simultaneously, using the electromagnetic vibrator, is put into oscillation with a low amplitude (it is possible to control the amplitude and the frequency of vibrations). A special instrumentation enables the measurement of friction force between the ball and the plate as well as Electrical Contact Potential (ECP) between them. Observing ECP, the condition of the lubricating film can be examined.

The test conditions are as follows:

– test duration: 75 min,
– frequency of the upper ball: 50 Hz,
– stroke length: 1.00 mm,
– bulk temperature of the fuel: 60ºC,
– load: from 50 to 200 g.

To the research on the impact of synthetic fuel components to turbine aircraft engines on the efficiency of the operation of lubricating additives, the following two tests were selected: BOCLE and HFRR. HFRR test, despite being dedicated to fuels for diesel engines, to a much greater extent than the BOCLE test, enables to test the formation of lubricating film and its influence on the wear of lubricated elements as well as friction coefficient [13]. In HFRR test, the energy released during friction remains in a small space (concentrated contact), which enables the analysis of the impact of improvers on energy transport, indispensable for forming the lubricating film of greater thickness.

3. Results

The results of BOCLE and HFRR tests are presented in Tab. 3 and on Fig. 4 and 5.

Tab. 3. The results of HFRR and BOCLE tests

No.	Tested sample	HFRR			BOCLE Wear [mm]
		Wear [μm]	Average film thickness [%]	Average friction coefficient	
1.	JET	770	1.1	0.6144	0.90
2.	JET + CI/LI	800	0.8	0.7247	0.60
3.	JET + SDA	783	1.7	0.6538	0.80
4.	JET + CI/LI + SDA	738	0.5	0.7593	0.61
5.	HEFA	803	0.5	0.8105	0.98
6.	HEFA + CI/LI	782	1.0	0.6122	0.57
7.	HEFA + SDA	637	0.6	0.4691	0.81
8.	HEFA + CI/LI + SDA	763	1.9	0.6017	0.58
9.	Blend (JET + HEFA)	757	1.9	0.5814	0.89
10.	Blend + CI/LI	784	0.9	0.5636	0.62
11.	Blend + SDA	735	2.9	0.5971	0.79
12.	Blend + CI/LI + SDA	741	1.1	0.6216	0.60

The obtained results indicates influence of chemical structure of base fuels on the effectiveness of lubricating additive, detected by HFRR test and no such influence in case BOCLE test. The results of BOCLE test depends only on the presence of lubricating additive (CI/LI). It is well known that results of BOCLE test do not correlate with the results of HFRR one. The reason is in the mechanisms of lubricating film formation during each of these tests.

During BOCLE test fuel contacts with the surface of cylinder in lower part of cylinder and as thin film is transported to the friction zone located in upper part. There is no possibility to form thick film and balls wear depends on the interaction between fuels molecules, including molecules of lubricating additives, and the surface of lubricated elements (ball and cylinder). The efficiency of lubricating additive (CI/LI) does not depend on hydrocarbons structure of base fuel and the presence of SDA molecules. This leads to conclusion that protection of materials of ball and cylinder against wear is independent from base fuel and molecules of other additives.

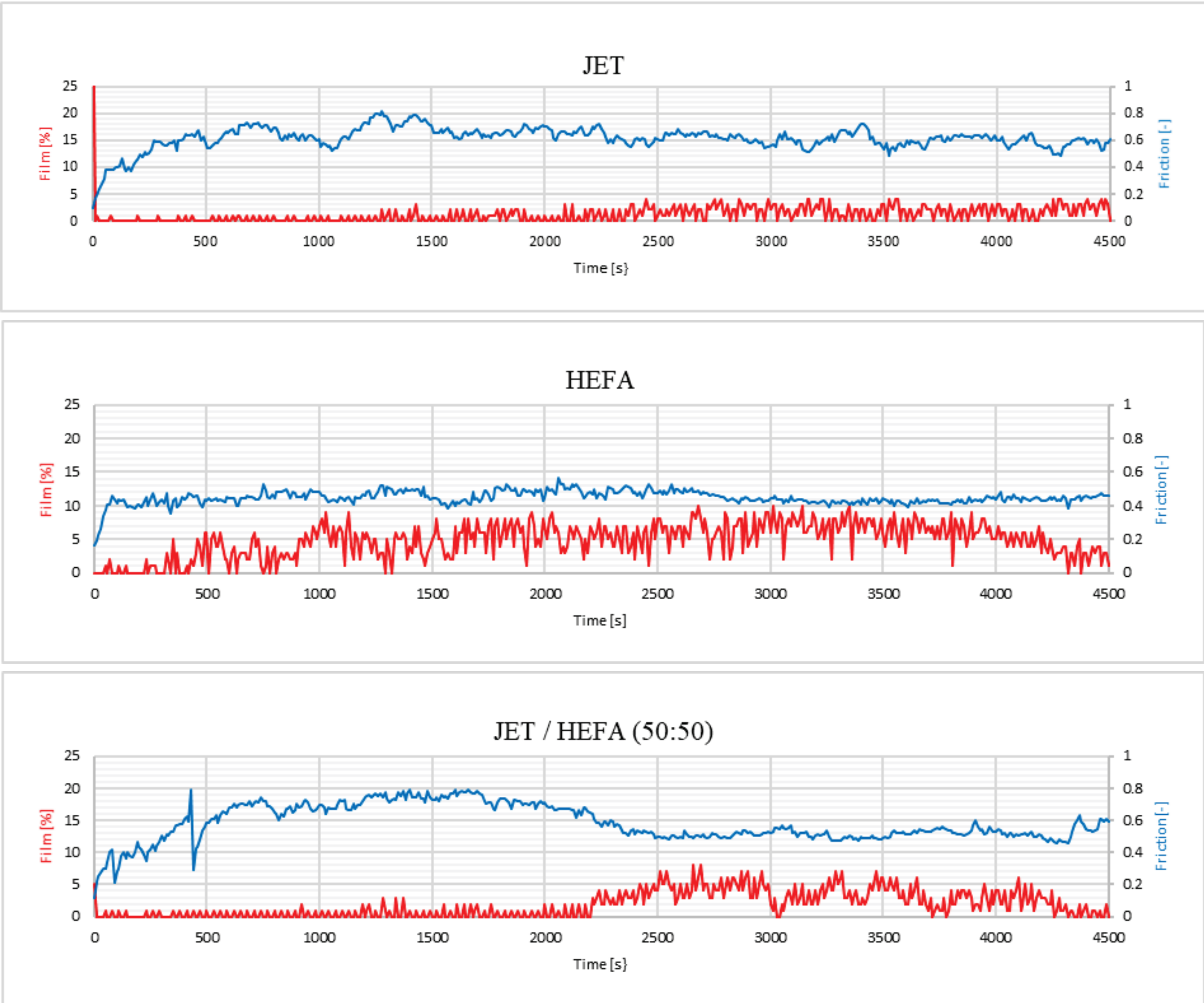


Fig. 4. Changes: friction (blue/left scale) and lubricant film [%] (red/right scale) during the HFRR test for petroleum fuel, synthetic fuel and their blend

Another situation was observed in case of HFRR test. Wear of balls (on the same level as during BOCLE test) depends on hydrocarbons structure of base fuel and on the presence of lubricating additive as well as SDA one. The HFRR test conditions enable thick film formation but variation of sliding speed and direction of balls movement make lubricating film unstable. It was found, that average film thickness is very small for all tested blends, but for this blends, which contain SDA, the tendency of thick film formation was observed. These blends give smaller wear, than obtained for blends, which do not form thicker film. During earlier research it was found, that more than 70% of final wear takes place before thick film formation. The difference between wear obtained for blends, which are able to create thick film, and other tested blends resulted from different fuels ability to create thick film.

It was found (see results of HFRR tests) that hydrocarbons structure of base fuel and presence of additive increasing ability to transport energy inside the lubricating film (SDA) influence on lubricating additives efficiency in wear decreasing This conclusion can be confirmed by comparison of wear level obtained for jet fuels and obtained for diesel fuel. Two-time smaller wear for diesel fuel and relatively high thickness of created film can by explain by the presence of PAH molecules in diesel fuel. These molecules can form molecular ordered structures, able to transport energy inside lubricating film. Mineral jet fuels as well as synthetic components of jet fuels do not contain PAH and it can be the reason that lubrication properties of all tested blends of fuels for turbine aircraft engines give significantly worse lubricity than diesel fuel.

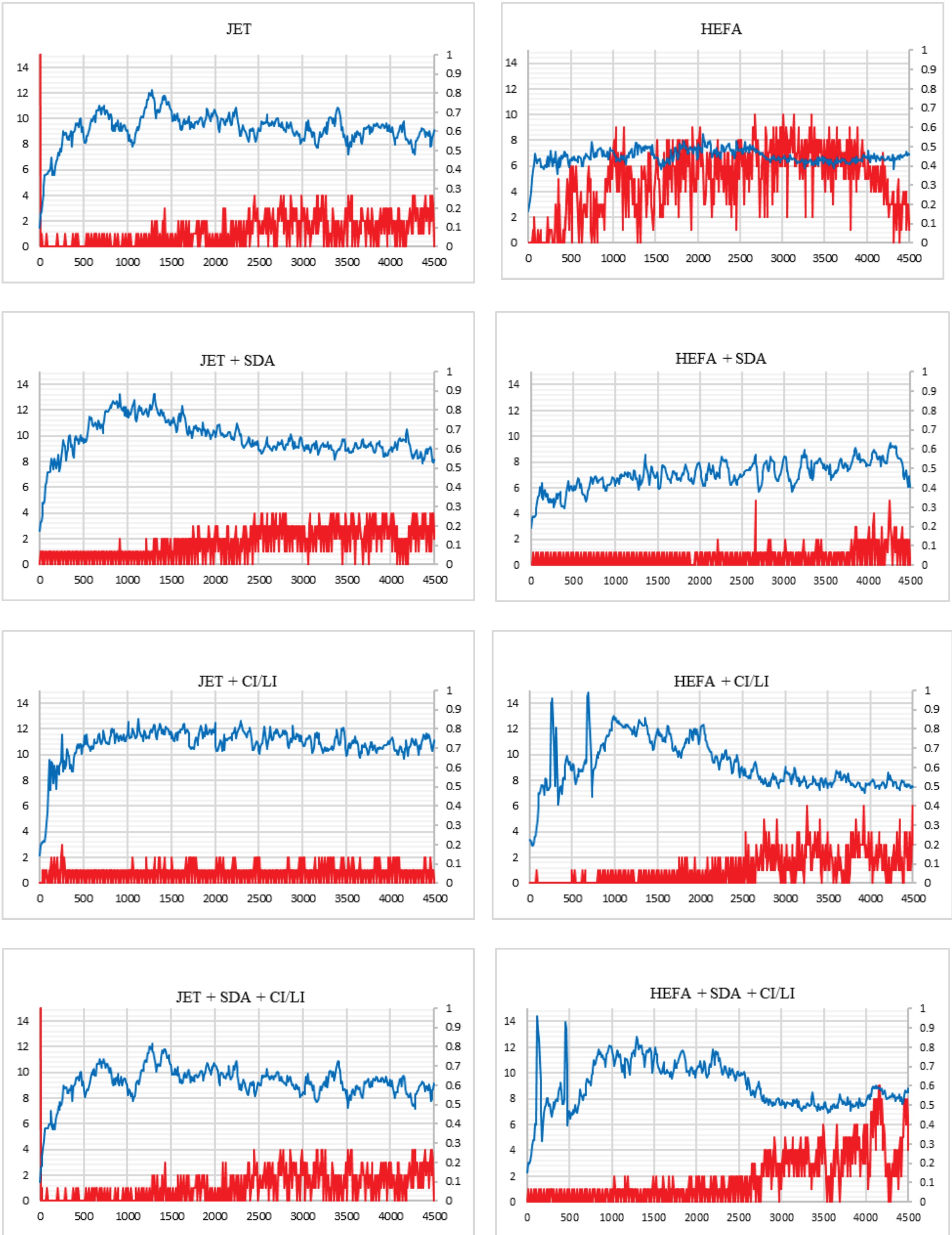


Fig. 5. Changes of friction (blue/left scale) and lubricant film [%] (red/right scale) during HFRR test [s] depending on the presence of additives: Static Dissipator Additives (SDA) and Corrosion Inhibitor/Lubricity Improvers (CI/LI)

4. Conclusions

The results shown in the paper preliminary confirm the hypothesis, that synthetic components of fuels change the concentration of ordered molecular structures (which are present in mineral part of fuels and which can be responsible for energy transport inside the lubricating film), what resulted in worse fuel ability to create protective film, and anti-electrostatic additive improves lubricity of blends of synthetic and mineral components.

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Manuscript received 09 January 2018; approved for printing 26 June 2018