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THE INFLUENCE OF SYNTHETIC HYDROCARBON ON LUBRICATING PROPERTIES OF FUELS FOR TURBINE ENGINES

WPŁYW SYNTETYCZNYCH WĘGLOWODORÓW PARAFINOWYCH NA WŁASNOŚCI SMARNE PALIW DO SILNIKÓW LOTNICZYCH

Key words: aviation fuels, tribological wear, lubricity, process modeling, synthetic paraffin hydrocarbons.

Abstract: Recently, steps have been taken to introduce synthetic hydrocarbons to aviation fuels as biocomponents. This action is an innovative change in the approach to aviation fuels. This new approach to the assessment of fuel properties requires a revision of the existing criteria for their quality assessment, including those relating to tribological properties. In the requirements for Jet fuel, only the BOCLE test simulating continuous circular motion was used to assess lubricity. Research on the use of fuels containing components with highly differentiated chemical compositions indicate that the BOCLE test may be an insufficient criterion for assessing the lubricity of fuels for aircraft turbine engines. An additional HFRR test modelling the processes accompanying the reciprocating friction that occurs in some lubricated elements of the fuel system has been proposed. This article presents the results of BOCLE and HFRR tests on a range of Jet A1 fuel mixtures and various synthetic paraffin hydrocarbons. A preliminary analysis of the observed effect of synthetic hydrocarbons on the results of both tests is presented.

Słowa kluczowe: paliwa lotnicze, zużycie tribologiczne, smarność, modelowanie procesu, syntetyczne węglowodory parafinowe.

Streszczenie: W ostatnim okresie podjęto działania zmierzające do wprowadzenia do paliw lotniczych węglowodorów syntetycznych jako biokomponentów. Działanie to ma charakter innowacyjnych zmian w podejściu do paliw lotniczych. To nowe podejście do oceny właściwości paliw wymaga rewizji dotychczasowych kryteriów ich oceny jakości, w tym odnoszących się do własności tribologicznych. W wymaganiach dla paliwa Jet dla oceny smarności stosowany był wyłącznie test BOCLE symulujący ruch ciągły po okręgu. Badania nad zastosowaniem paliw zawierających komponenty o silnie zróżnicowanym składzie chemicznym wskazują, że test BOCLE może być niewystarczającym kryterium oceny smarności paliw do turbinowych silników lotniczych. Zaproponowano dodatkowy test HFRR, modelujący procesy towarzyszące tarciu w ruchy posuwisto-zwrotnym, który występuje w niektórych smarowanych elementach układu paliwowego. W artykule zaprezentowano wyniki badań w testach BOCLE i HFRR gamy mieszanek paliwa Jet A1 i różnych syntetycznych węglowodorów parafinowych. Przedstawiono wstępną analizę zaobserwowanego wpływu syntetycznych węglowodorów na wyniki obu testów.

INTRODUCTION

The development of air transport, especially the one seen before the pandemic, made aviation, like road transport, one of the important emitters of GHG. One of the directions of activities aimed at limiting GHG emissions by aviation is the introduction of biofuels. Conventional fuel, widely used in military and civil aviation transport, is JET-A1 fuel, used to drive turbine engines. In the USA and Europe, steps were taken to introduce biocomponents into aviation fuels – synthetic hydrocarbons.

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This is an innovative change in the approach to aviation fuels. The introduction of synthetic components to the fuel composition completely changes the situation: the experience so far needs to be verified.

This requires the verification of the assessment of fuel properties and consequently requires a revision of the existing criteria for their quality assessment, including those relating to tribological properties of fuels. The chemical structure and properties of synthetic fuel components depend on the technology of their production. Due to the special requirements related to flight safety, biofuels / hydrocarbon biocomponents intended for aircraft turbine engines have to be approved by engine manufacturers. However, this approval applies not only to the type / technology of the biofuel, but also to the raw material and plant producing the biofuel. This was reflected in the provisions of ASTM D7566-19 and Def Stan 91-091 standards. **[L. 1, 2]** Currently, the following technologies of synthetic hydrocarbons production are used: Hydroprocessed Esters and Fatty Acids (HEFA), Fischer – Tropsch (FT) technology, biocomponent obtained by Fischer – Tropsch technology + aromatic hydrocarbons of non-petroleum origin (FT/A), Alcohol to Jet ATJ and Synthesized Izoparaffines (SIP) and Catalytic Hydrothermolysis Jet (CHJ) **[L. 3–12]**. The selected synthetic components have been approved for use in blends with conventional Jet A fuels, as defined by the ASTM D 7566 standard.

One of the important devices in the supply system of turbine engines is the fuel pump. Fuel must effectively lubricate this pump. The lubrication efficiency depends on the one hand on the properties of the fuel, and on the other hand, on the design and operating conditions of the lubricated device. Laboratory tests to assess the lubricity of fuels should model the processes that are most influenced by new fuels containing synthetic components.

The BOCLE test used so far to assess the lubricity of aviation fuels simulates the sliding of a pusher on a rotating disk. This test does not simulate the lubrication process of a reciprocating pump piston, for example. The introduction of new, synthetic components to aviation fuel, however, may disrupt the lubrication process of such devices. Hence, it was considered advisable to supplement the set of lubricity assessment tests with the HFRR test in the research presented in the article. The HFRR test simulates the reciprocating lubrication process.

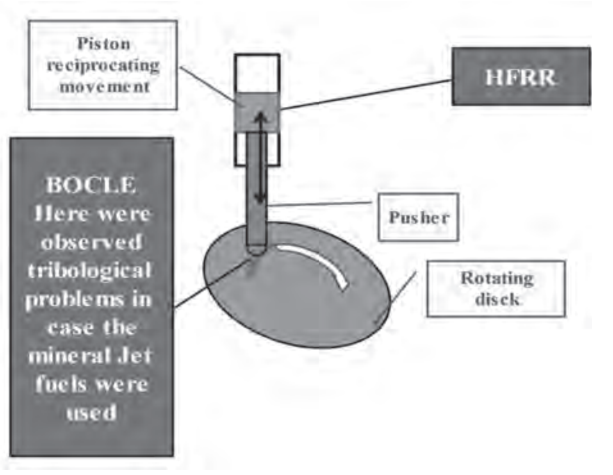

Fig. 1. The idea of lubricity tests of fuels for aircraft turbine engines
Rys. 1. Idea badań smarności paliw do lotniczych silników turbinowych

The aim of the paper is determination of the influence of synthetic fuel components for aircraft turbine engines on the lubrication of fuel pump elements in aircraft.

TEST METHODS AND MATERIALS

Tests methods

The lubricity of turbine aircraft fuels was examined using a BOCLE test (Ball on Cylinder Lubricity Evaluator) **[L. 13]**. The frictional matching consists of the immovable ball which is pressed axially to the external surface of the rotating ring (**Fig. 1**). The test conditions are as follows:
- Rotating speed of cylinder: 240 rpm,
- Load: 1 000 g,
- Test duration: 30 min,
- Fuels temperature: 25°C.

The HFRR (High-Frequency Reciprocating Rig) test simulates the process of piston – cylinder lubrication much better than BOCLE test **[L. 14]**. The test conditions are as follows:
- Test duration: 75 min,
- The frequency of the upper ball: 50 Hz,
- Stroke length: 1000 µm,
- The bulk temperature of the fuel: 60°C, and
- Load: 50 to 200 g.

The conditions in the friction junction of the BOCLE apparatus differ significantly from the prevailing conditions in real fuel pumps; however, operational experience has shown that, if the fuel meets the lubricity requirements, the lubrication efficiency of the actual fuel pumps is adequate.

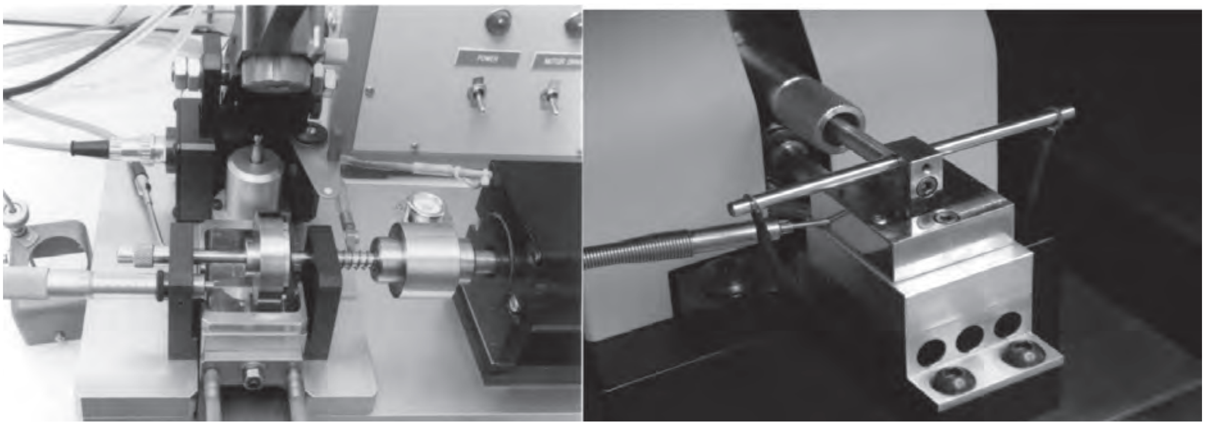

Fig. 2. The BOCLE and HFRR apparatus
Rys. 2. Aparat BOCLE i HFRR

Such conclusions, however, can only be drawn for mineral fuels (Jet A-1), to which the operational experience relates. The experience of using mineral fuels cannot be "automatically" transferred to blends of petroleum fuels and synthetic components.

Materials

To determine the effect of synthetic fuel components for aircraft turbine engines on the lubrication capacity of aircraft fuel pump components, tribological tests of various Jet A-1 fuel blends with commercial synthetic components (ATJ, HEFA-UCO) were carried out.

The research also used the so-called "Surrogate Fuels," i.e. single hydrocarbons or mixtures of several hydrocarbons, which are considered models of fuels or fuel components **[L. 15]**. The series of Fuel Patterns containing synthetic hydrocarbons (Surrogate Fuels) was prepared.

Table 1. Tested blends of Jet A1 and synthetic components
Tabela 1. Badane mieszanki Jet A1 i komponentów syntetycznych

The concentration of Jet A-1 in the blend [%]	The type and concentration of synthetic component in the blend [%]	Blend symbol
50 (hydrotreating technology)	HEFA 50	B1
75 (hydrotreating technology)	ATJ 25	B2
50 (Merox technology)	HEFA 50	B3
75% (Merox technology)	ATJ 25	B4
0	ATJ 100	ATJ
50 (hydrotreating technology)	ATJ 50	50% ATJ
0	HEFA (UCO) 100	UCO

Weight% of the mixture	Weight% of the mixture	Research blend symbol
5% B1	95% B2	B1/B2
5% B2	95% B1	B2/B1
5% B3	95% B4	B3/B4
5% B4	95% B3	B4/B3

Table 2. Prepared models of hydrocarbon biocomponents
Tabela 2. Opracowane modele biokomponentów węglowodorowych

	Concentration of the hydrocarbon in the Model			
	OCTAN (C_8)	**UNDEKAN (C_{11})**	**PENTADEKAN (C_{15})**	**HEPTADEKAN (C_{17})**
Model 1	0	0	50% (V/V)	50% (V/V)
Model 2	50% (V/V)	50% (V/V)	0	0

Table 3. Prepared Patterns of Biofuels
Tabela 3. Przygotowane Wzorce Biopaliw

Pattern symbol	Pattern composition	Pattern symbol	Pattern composition
W0H	100% Jet A1 ((hydrotreating technology)	W4	75% JET A1 + 25% Model-2
W1	90% JET A1 + 10% Model-1	W5	50% JET A1 + 50% Model-1
W2	90% JET A1 + 10% Model-2	W6	50% JET A1 + 50% Model-2
W3	75% JET A1 + 25% Model-1	–	–

RESULTS

The results of tribological BOCLE and HFRR tests are presented in **Figs. 3–6**. All results are presented as relative, percentage measurements of lubricity A, determined by the relationship:

$$A_{HFRR} = (X - X_{WOH}/X_{WOH})100\% \quad (1)$$

$$A_{BOCLE} = (X - X_{WOH}/X_{WOH})100\% \quad (2)$$

where:
A_{HFRR} – the measure of lubricity related to HFRR test,
A_{BOCLE} – the measure of lubricity related to BOCLE test,
X – test result (wear),
X_{WOH} – wear obtained for Jet A1 fuel (hydrotreating technology).

The presented research results of the Patterns indicate a significant influence of synthetic hydrocarbon components on the fuel lubricity. This effect depends on the structure of the hydrocarbons added to the conventional Jet A1 fuel. Heavier hydrocarbons (C15 and C17) improve lubricity more effectively, but light hydrocarbons (C8 and C11) also have a positive effect on fuel lubricity; however, commercial synthetic components (also consisting of hydrocarbons) behave differently. ATJ, both pure and 50% blended with Jet A1, has the same lubricity as pure Jet A1 fuel. Only the UCO component shows higher wear in the BOCLE test than that obtained for the Jet A1 fuel. This can be explained by interaction of the synthetic hydrocarbons with the hydrocarbons of the Jet A1 fuel. This is confirmed by the test results of Jet A1, ATJ and UCO: B1 / B2, B2 / B1, B3 / B4 and B4 / B3 mixtures. Depending on the concentration of the individual components, the lubricity of the mixture is better or worse than conventional Jet A1 fuel. These effects cannot be directly related either to the concentration of the lubricity additive (added only to Jet A1 fuel) or to the viscosity of the mixture.

The above conclusions can also be applied to the HFRR test. As shown in **Fig. 7**, the trend of changes in lubricity determined by both of these tests is the same. This indicates that the above-mentioned interactions occur under different operating conditions of the lubricated device.

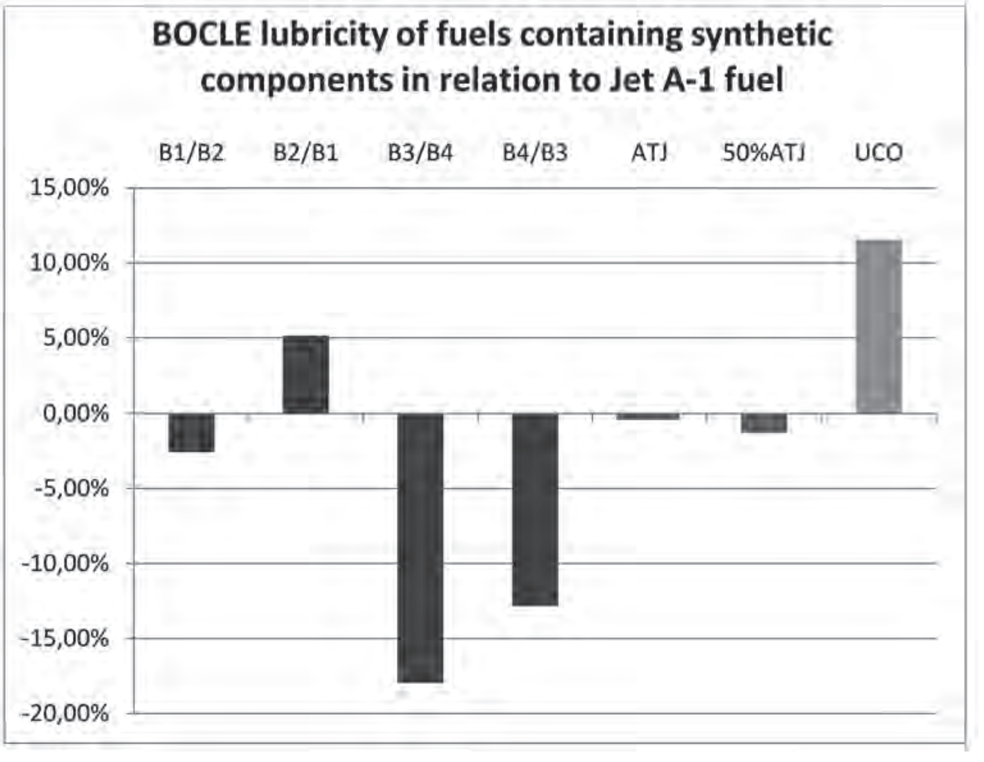

Fig. 3. Influence of synthetic components and their blends on lubricity by BOCLE method in relation to Jet A-1 fuel
Rys. 3. Wpływ składników syntetycznych i ich mieszanek na smarność metodą BOCLE w odniesieniu do paliwa Jet A-1

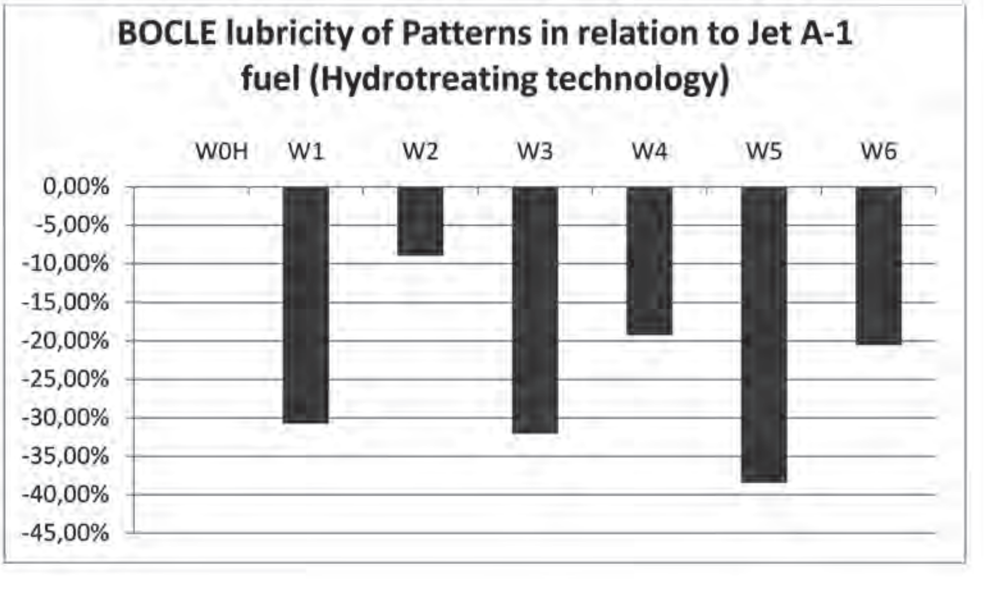

Fig. 4. The influence of the Patterns on the lubricity by the BOCLE method in relation to the Jet A-1 fuel
Rys. 4. Wpływ Wzorców na smarność metodą BOCLE w odniesieniu do paliwa Jet A-1

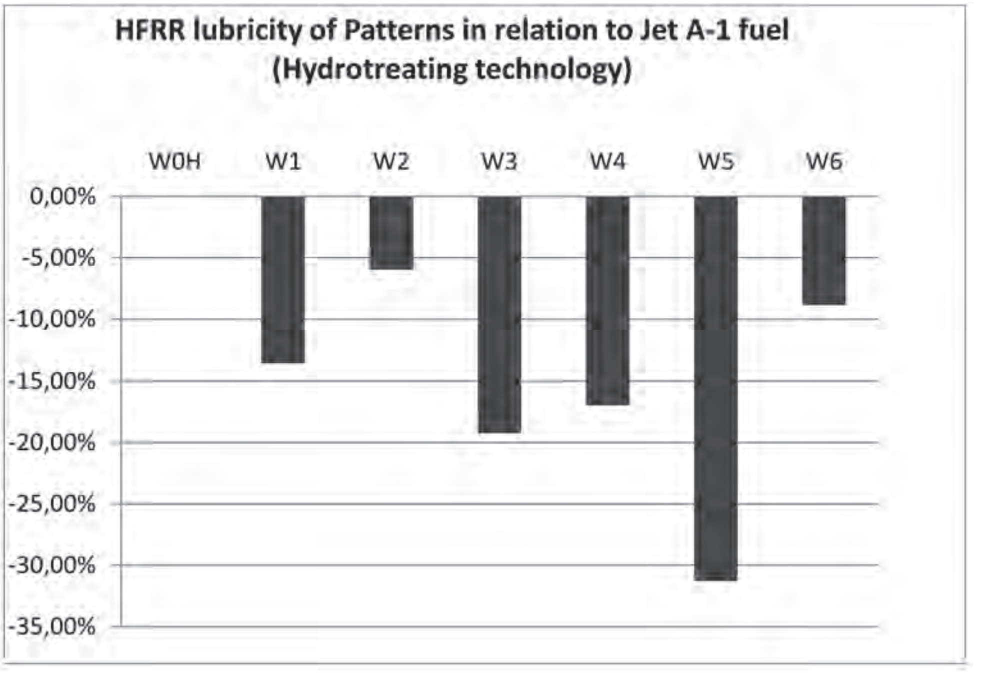

Fig. 5. The influence of the Patterns on the lubricity by the HFRR method in relation to the Jet A-1 fuel
Rys. 5. Wpływ Wzorców na smarność metodą HFRR w odniesieniu do paliwa Jet A-1

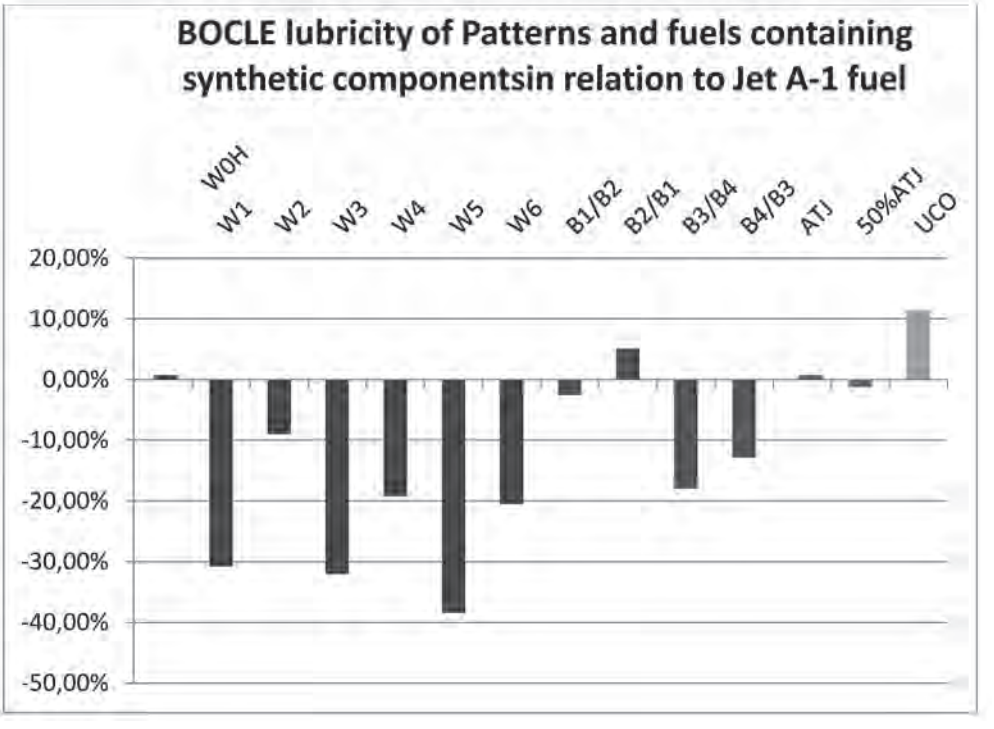

Fig. 6. Influence of Patterns of synthetic components, test mixtures on lubricity using the BOCLE method for Jet A-1 fuel
Rys. 6. Wpływ Wzorców składników syntetycznych, mieszanin testowych na smarność metodą BOCLE dla paliwa Jet A-1

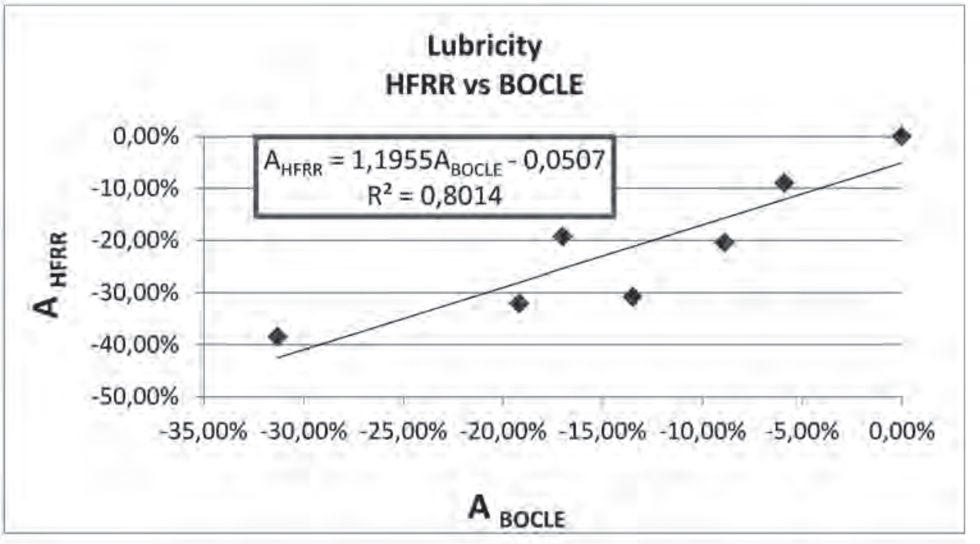

Fig. 7. Comparison of the results of the standard lubricity assessment using the HFRR and BOCLE methods
Rys. 7. Porównanie wyników standardowej oceny smarności metodami HFRR i BOCLE

CONCLUSIONS

Tribological tests carried out using the standard method for BOCLE aviation fuels and additionally in the HFRR test allowed coming to the following conclusions:

1. The effect of synthetic commercial components (ATJ, HEFA-UCO) depends on their chemical structure:
   - ATJ in the tribological test behaves like the mineral Jet A-1 fuel,
   - HEFA-UCO shows deterioration of lubricity in relation to Jet A-1 fuel.
2. Mixtures of various synthetic fuels (B1 / B2, B2 / B1, B3 / B4, B4 / B3) in lubrication processes behave in a difficult to predict based on the results of tests of Jet A-1 fuel mixtures and single synthetic components (B1, B2 , B3, B4) – clear deviations from additivity.
3. The developed Patterns of synthetic fuels were used to study the effect of the hydrocarbon composition of synthetic components on the lubricity of mixtures with JetA-1 fuel.
4. The research carried out in the BOCLE and HFRR tests allowed us to establish a significant influence of the chemical structure of synthetic hydrocarbons on the lubricity.
5. Assessment of the lubricity of fuels containing synthetic components based on the results of the BOCLE and HFRR tests leads to similar conclusions. However, the Patterns examined behaved in a slightly different way in these tests.

In further studies, greater use of the HFRR test is planned due to the possibility of measuring the friction coefficient during the test, which may be an important additional criterion for the assessment of aviation fuels. The authors plan to conduct research using the HFRR test.

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