

10. Технический справочник по обработке воды: в 2 т. Т. 1; пер. с фр. [Текст]. – СПб.: Новый журнал, 2007.
11. Акользин, П. А. Коррозия и защита металла теплоэнергетического оборудования [Текст] / П. А. Акользин. – М.: Энергоиздат, 1982. – 303 с.
12. Кишневский, В. А. Исследование процессов карбонатных отложений на теплообменных поверхностях конденсаторов [Текст] / В. А. Кишневский, В. В. Чиченин // Восточно-Европейский журнал передовых технологий. – 2014. – Т. 3, № 8 (69). – С. 52–58. doi: 10.15587/1729-4061.2014.25191
13. Кишневский, В. А. Методика расчета водно-химического режима комплексной оборотной системы охлаждения с рециркуляцией [Текст] / В. А. Кишневский, В. В. Чиченин, И. Д. Шуляк // Восточно-Европейский журнал передовых технологий. – 2013. – Т. 6, № 8 (66). – С. 10–14. – Режим доступа: <http://journals.urau.ua/eejet/article/view/19428/17072>
14. Чиченін, В. В. Підвищення ефективності кондиціонування теплоносіїв в освітлювачах комплексних зворотних систем охолодження енергоустановок [Текст]: автореф. дис. ... канд. техн. наук / В. В. Чиченін. – Одеса, 2010. – 19 с.
15. Peev, T. Some Data on the Dynamics of Corrosion Processes in Water Circulation Cooling Systems [Text] / T. Peev, V. Taseva, I. Mitov, V. Kunev, D. Paneva, V. Bonev // Monatshefte fuer Chemie/Chemical Monthly. – 2001. – Vol. 132, Issue 10. – P. 1181–1188. doi: 10.1007/s007060170033

Досліджено протизносні властивості палива для ПРД, двох видів біокомпонентів, отриманих з ріпакової олії та їх сумішей. Встановлено, що змащувальна здатність біокомпонентів є вищою у порівнянні з нафтовим паливом для ПРД. Додавання біокомпонентів призводить до зміцнення граничної плівки та поліпшує протизносні властивості паливних сумішей. Встановлено, що модифікування біокомпонентів підвищує їх змащувальну здатність у порівнянні зі стандартними біокомпонентами

Ключові слова: паливо для ПРД, альтернативне паливо, зношування, біокомпоненти, змащувальна здатність, навантаження до задирання, тертя

Исследованы противозносные свойства топлива для ВРД, двух видов биоконпонентов, полученных из рапсового масла и их смесей. Установлено, что смазывающая способность биоконпонентов выше по сравнению с нефтяным топливом для ВРД. Добавление биоконпонентов приводит к упрочнению граничного слоя и улучшает противозносные свойства топливных смесей. Установлено, что модифицирование биоконпонентов повышает их смазывающую способность по сравнению со стандартными биоконпонентами

Ключевые слова: топливо для ВРД, альтернативное топливо, износ, биоконпоненты, смазывающая способность, нагрузка задира, трение

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EXPERIMENTAL STUDY ON ANTIWEAR PROPERTIES FOR BLENDS OF JET FUEL WITH BIO-COMPONENTS DERIVED FROM RAPESEED OIL

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1. Introduction

Over the last years, increasing attention is paid to the question of traditional energy sources replacement with

their alternative analogues [1, 2]. The question is particularly acute for transport sector [3–5]. During last decade alternative fuels have been used not only motor transport, but for aviation as well. Today numbers of international

organizations, such as ICAO (International Civil Aviation Organization), IATA (International Air Transport Association) pay much attention to the questions of making civil aviation „green”.

One of the main tasks in the field of production and use of aviation fuels and lubricants is to expand the resource base and to develop progressive technologies for the production of aviation fuels. At the same time, alternative aviation fuels must meet a number of requirements related to efficiency, reliability and durability of aviation technics [2, 3].

2. Literature overview and problem statement

Today, there is great variety of alternative jet fuels as well as technologies of their production. One of the most developed and widely used renewable jet fuels is hydrogenated synthetic paraffin kerosene that is well described in [4]. Biofuel is made of plant and (or) animal fat-containing feedstock. Except that, there are some other renewable fuels, made of biomass via FT-synthesis, made of alcohols, various algae and even industrial and household waste. However, all of these biofuels can be added to conventional petroleum jet fuels in quantity up to 50 % [5–9].

Another possible way to replace conventional jet fuels with renewable fuels is use of methyl (ethyl) esters of plant oils or animal fats [6, 7]. Primarily these biofuels have become popular as a fuel substitute for motor transport, but lately they've been proposed to be used as components for jet fuel [9, 10]. This kind of biofuel is produced via esterification of plant oils with methyl or ethyl alcohols [3, 7]. According to the developed technology up to 30 % (vol.) of biofuel can be added to conventional jet fuel [10].

However, today properties of various biofuels are not studied completely. Special attention must be paid to research of exploitation properties of alternative fuels. Other words it is necessary to study the impact of such fuels on aircraft equipment and details during long-term use.

It is noted [3, 11, 12] that alternative jet fuels, obtained via FT-synthesis are characterized by low lubricity that in future may cause premature wear of engine details [3, 8, 9]. At the same time, there is a lack of experimental data on lubricity properties of plant oils esters [12–14]. There are only some information about esters application as a substitute of conventional diesel fuel [14–17].

3. Purpose and objectives of the study

The key purpose of this paper is to study the antiwear properties of blended jet fuels containing biocomponents made of rape oil.

In accordance with the set goal the following research objectives are identified:

1. Research of rapeseed oil fatty acids methyl esters influence on lubricating properties of jet fuels.
2. Studying the mechanism of biocomponents action as an improver of fuel lubricating properties.
3. Comparative analysis of lubricity of two kinds of investigated biocomponents.
4. Substantiation of possibility of biocomponents use as a partial substituent to conventional jet fuel.

4. Experimental methodology

4. 1. Sample characterization

Lubricity of jet fuel, two kinds of biocomponents and their blends with jet fuel was investigated during the experiment. Jet fuel was presented by traditional oil-derived fuel for jet engines of grade Jet A-1 that meets the requirements of ASTM D1655. Biocomponents were presented by fatty acids methyl esters (FAME) of rape oil, meeting the requirements of EN 14214 and fatty acids methyl esters of rape oil that are specially modified for application as a component of jet fuel (FAME(M)). The modification was done by vacuum distillation according to the developed technology [10]. The content of biocomponents in fuel blends was: 10–50 % (vol.).

4. 2. Description of testing device and research methodology

Usually antiwear properties of jet fuels are estimated by the wear value of specific friction pair [18, 19]. Value of scuffing load may be also used to estimate this characteristic. Antiwear properties of fuel samples were investigated using a T-02U four-ball tester that consists of the testing device and a metering-control system. The mechanical part (testing device) includes body, power train, friction pair load bearing drive, ball cup assembly and a base. The friction pair (Fig. 1) consists of three lower balls fixed in a clamp and loaded with appropriate force applied by the top ball mounted on a spindle rotating with a determined speed [21].

The typical ball bearings of 1/2" diameter were used for the tests. The bearings are made of GCr15 bearing steel with hardness of 60–65 HRC. The mechanical system allows linear increasing of the load applied to the friction pair during a test. The metering-control system consists of a dedicated microprocessor based controller, asynchronous motor controller and a computer with special control software [21].

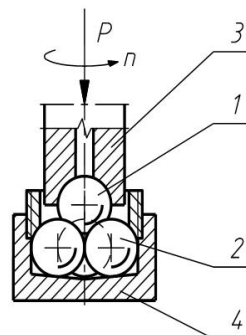


Fig. 1. Four ball tester friction pair [24]: 1 – top ball, 2 – bottom balls, 3 – spring clamp, 4 – balls cup

The tests were conducted under conditions of gradual load increase. The rotation speed during tests was 500 rpm, with the load increase rate of 409 N/s. The initial temperature of the fuel sample at the start of the test run was 60 ± 1.0 °C. Within the scope of this test, by definition a friction pair seizure is said to have occurred once the boundary friction torque M_T , of 10 Nm is exceeded. This value is determined by the durability of the top ball shank in the friction pair. The friction torque M_T and the linearly increasing friction pair load P were recorded during testing.

The principle of the method is determining of the scuffing load applied to the friction pair [22]. Load P , where the friction

torque value starts to increase rapidly is called the scuffing load and denoted as P_S . The values of P_S were reading from files recorded during run test. The reading errors of P_S have been estimated to be ± 20 N. Thus, the fuel sample with the highest value of applied scuffing load is considered to have the best antiwear properties. Other words, it means that the boundary film of this fuel sample demonstrated the highest durability to breaking.

5. Investigation of scuffing load of fuel samples

The following Fig. 2–14 depict the friction torque, friction pair load and friction coefficient that were recorded during tests. The scuffing load describing the criteria for lubricity assessment in the chosen test methodology is marked.

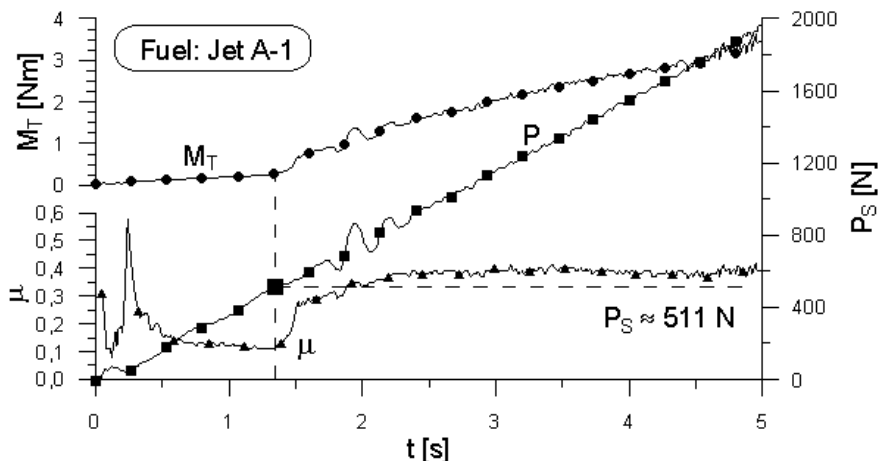


Fig. 2. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for pure jet fuel of grade Jet A1 fuel: P_S – scuffing load

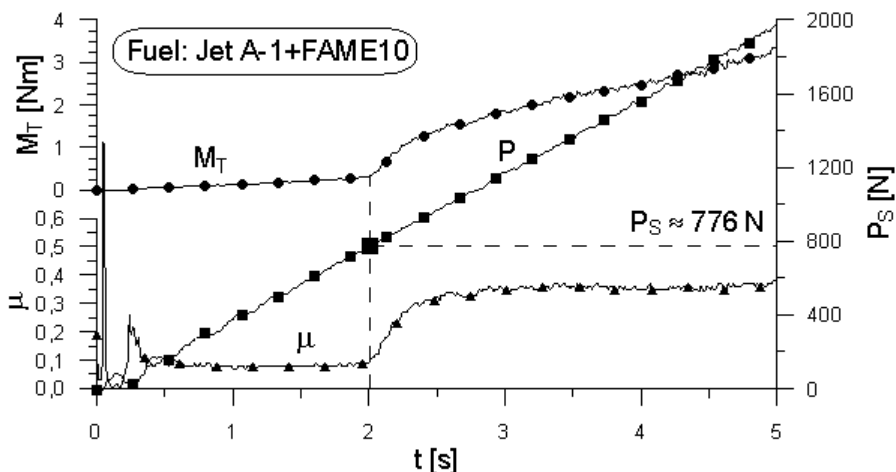


Fig. 3. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 10 % of biocomponent FAME: P_S – scuffing load

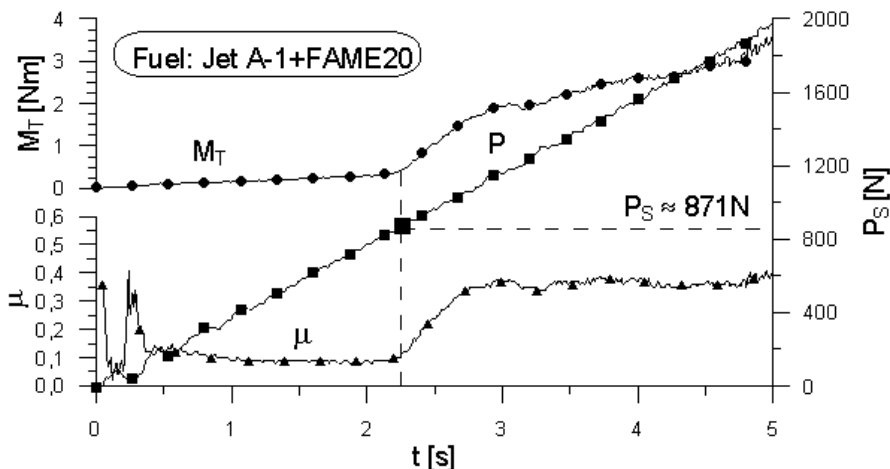


Fig. 4. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 20 % of biocomponent FAME: P_S – scuffing load

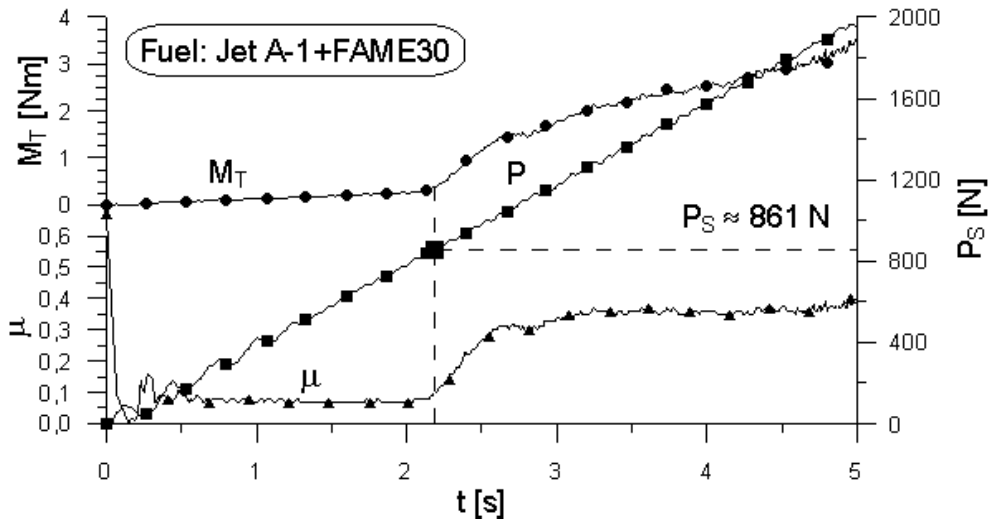


Fig. 5. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 30 % of biocomponent FAME: P_S – scuffing load

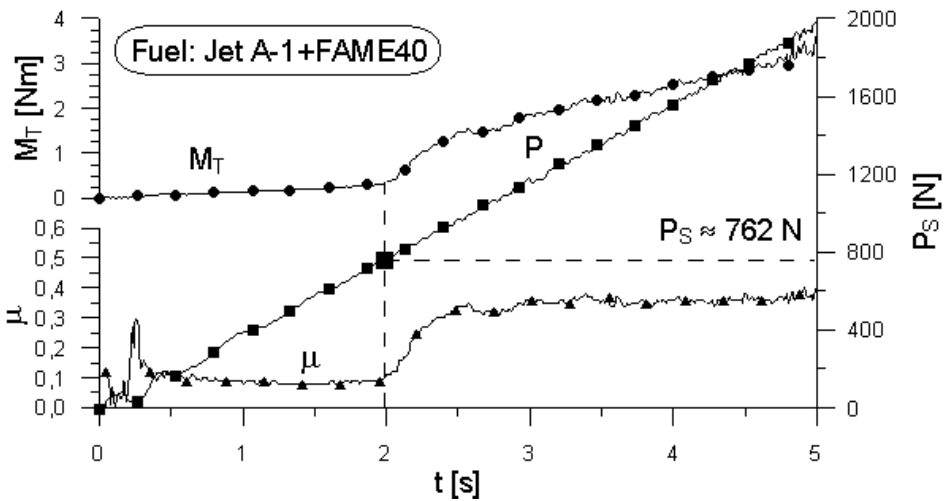


Fig. 6. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 40 % of biocomponent FAME: P_S – scuffing load

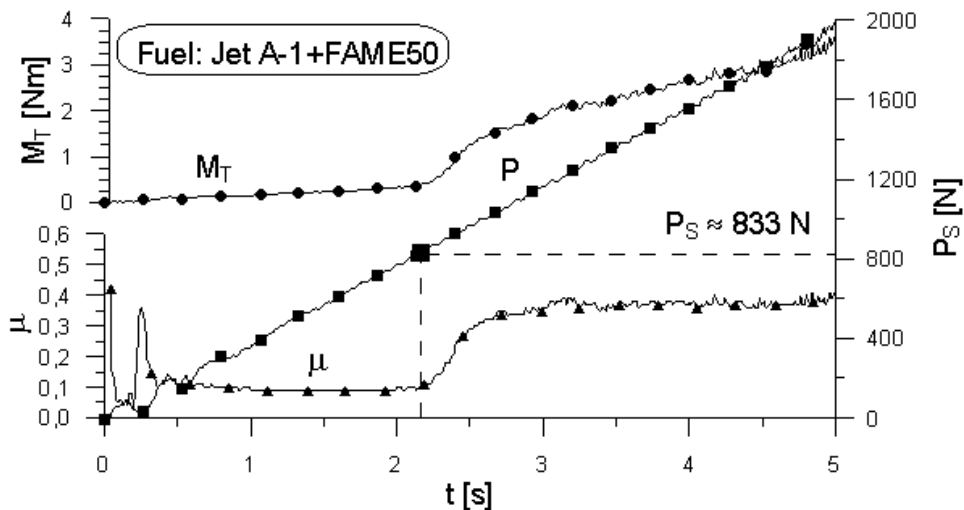


Fig. 7. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 50 % of biocomponent FAME: P_S – scuffing load

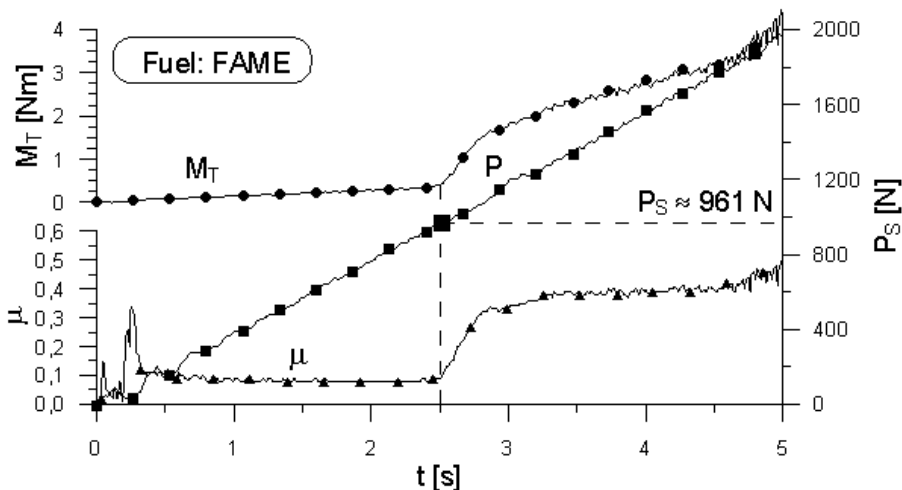


Fig. 8. Friction pair loading force P, friction torque M_T and friction coefficient μ as a function of testing run time t for pure biocomponent FAME: P_S – scuffing load

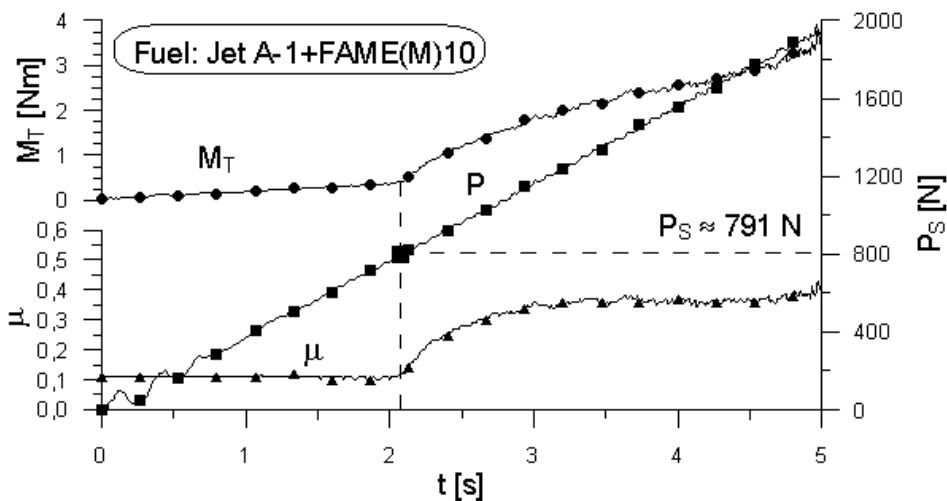


Fig. 9. Friction pair loading force P, friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 10 % of modified biocomponent FAME(M): P_S – scuffing load

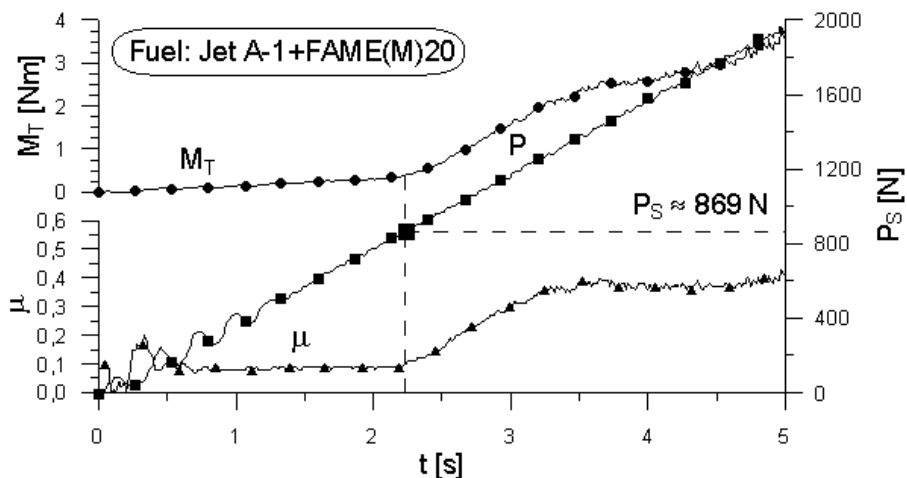


Fig. 10. Friction pair loading force P, friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 20 % of modified biocomponent FAME(M): P_S – scuffing load

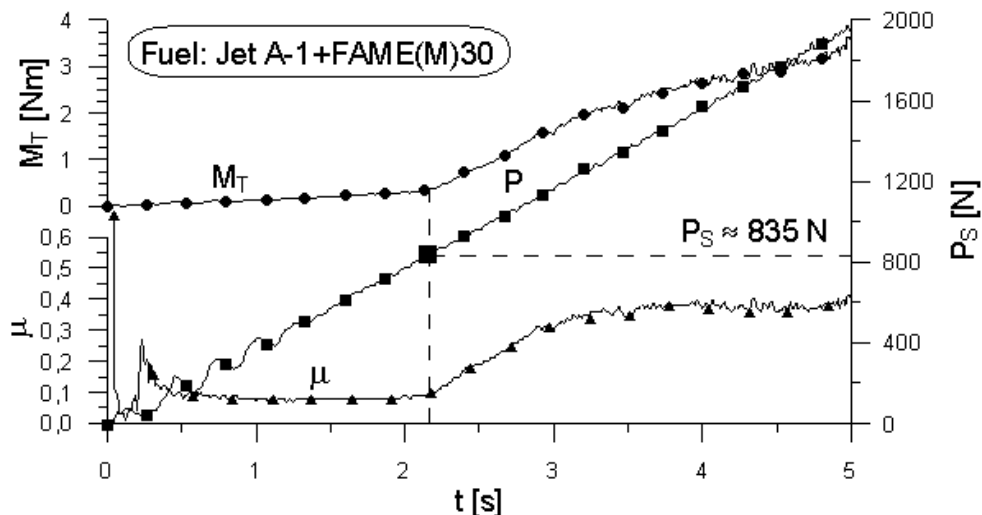


Fig. 11. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 30 % of modified biocomponent FAME(M): P_S – scuffing load

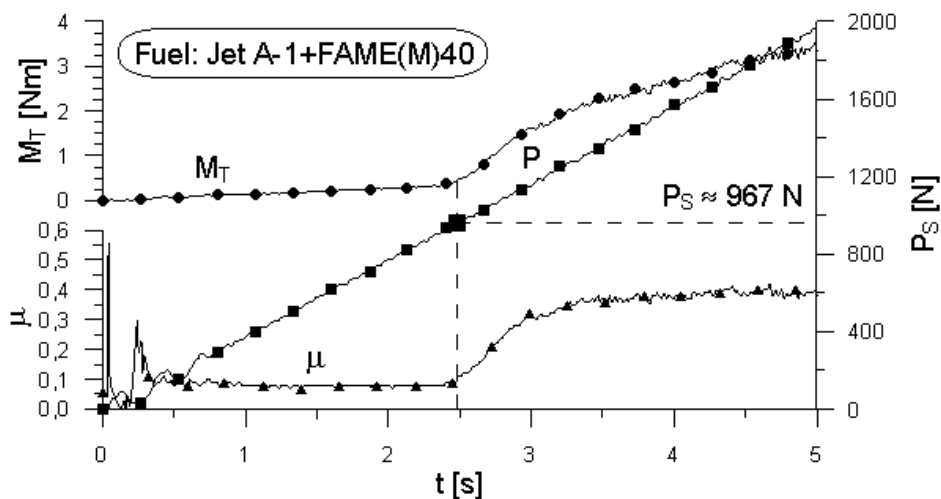


Fig. 12. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 40 % of modified biocomponent FAME(M): P_S – scuffing load

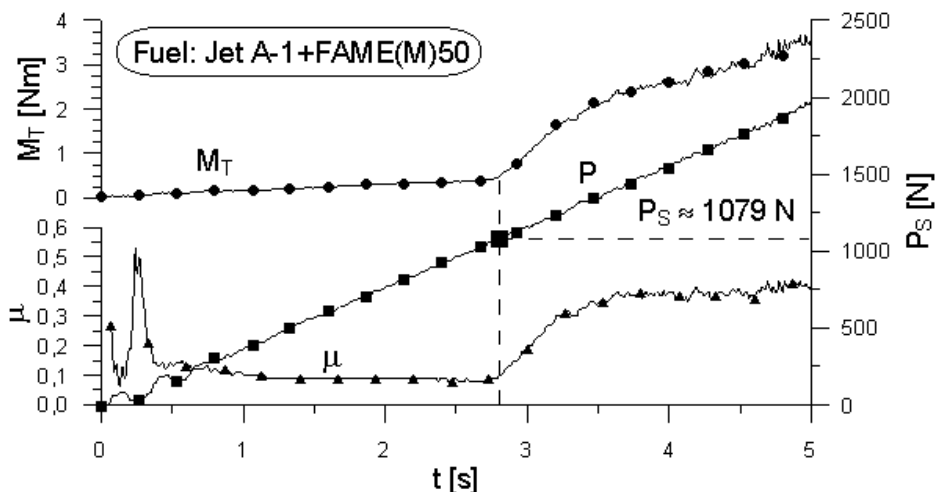


Fig. 13. Friction pair loading force P , friction torque M_T and friction coefficient μ as a function of testing run time t for blend fuel Jet A1 with 50 % of modified biocomponent FAME(M): P_S – scuffing load

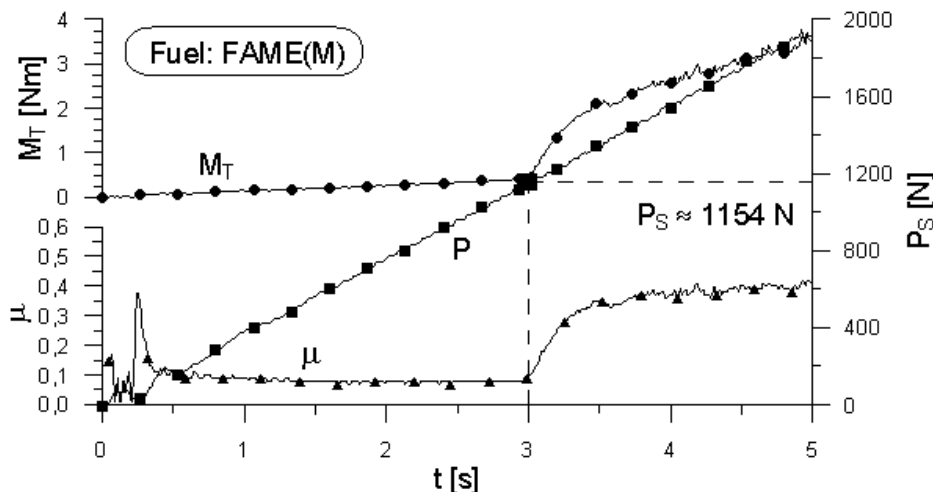


Fig. 14. Friction pair loading force P, friction torque M_T and friction coefficient μ as a function of testing run time t for pure modified biocomponent FAME(M): P_S – scuffing load

Thus, antiwear properties of jet fuel, two kinds of biocomponents derived from rapeseed oil and their mixtures were studied according to their scuffing load. The obtained results require further analysis and discussion.

6. Discussion of the results

In order to summarize the obtained results, the values of scuffing load P_S for each fuel sample were recorded and shown in Fig. 15.

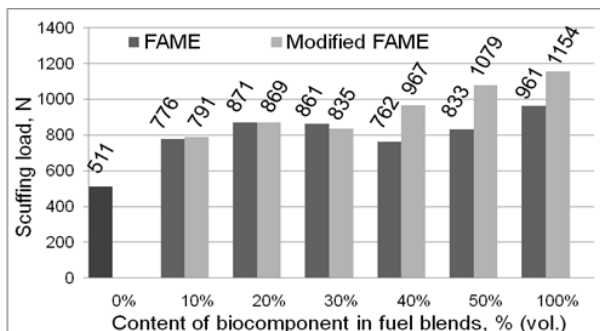


Fig. 15. Change of friction pair scuffing load depending on the content of biocomponent in jet fuel blends

The presented results show that the conventional jet fuel of grade Jet A-1 has demonstrated the lowest value of scuffing load – 510 N. At the same the highest values of scuffing load were observed for both types of biocomponents: 960 N – for rape oil FAME and 1150 N – for modified rape oil FAME. Taking conventional jet fuel as a reference sample we can easily conclude that use of rape oil esters positively influence the lubricity properties of jet fuel. Let us consider the mechanism of this effect.

Antiwear properties of jet fuels determine reliability and operational life of fuel system friction pairs in particular [18]. Jet fuel cannot produce a continuous protecting film so aviation components normally operate in the boundary lubrication regime where the load is carried partly by the fluid film and partly by the contacting surfaces. The most likely explanation for wear in aviation systems is a simple corrosive wear process later

followed by severe adhesive wear and scuffing as the component dimensions become reduced beyond tolerable limits [18, 19].

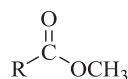
Fuel lubricating properties depend on chemical composition, viscosity, thermal-oxidation stability, content of mechanical impurities, and presence of surfactants [18–20]. In case of high unit loads the semi-liquid friction is usually observed – that is when wearing surfaces are not completely divided by the fuel. In these conditions the antiwear properties of jet fuels are determined by:

- 1) fuel viscosity that provides hydrodynamic effect of wearing surfaces division by liquid layer;
- 2) presence of surfactants in fuel that form high strength absorption layer at the wearing surface and divide wearing surfaces with decreasing of friction coefficient and details wearing.

Surfactants in fuel cause its surface activity – ability of fuel or its components to absorb at the surface of metal, form the boundary film and thus prevent dry friction of details. Solid bodies are characterized by high surface tension and their surface contacting to multicomponent liquid adsorbs substances that decrease this tension [23, 24]. Physical mechanism of adsorption at solid surface is explained by electrostatic interaction of polar molecules with electric field of particles that form solid surface, for example, metal ions [19, 20].

Fuel hydrocarbons are non-polar and almost do not protect friction pairs from wear. Substances, which may be contained in jet fuel naturally and which are considered to be surface active, are gums, organic acids and other oxygen-containing compounds, sulfur-organic and nitrogen-organic compounds. At the same time presence of the mentioned substances is undesired, from the point of view of thermal stability and corrosion properties of fuel [25].

Biocomponents used in jet biofuel blends are the products of reaction between complex esters of glycerine and higher fatty acids (triglycerides) and simple alcohol (methanol or ethanol). Molecules of biocomponents are complex esters, which contain residuals of fatty acid and alcohol. Fatty acids esters have different number of carbon atoms in chain and different number of double bonds [26, 27]. General formula of FAME looks as following:



where R – radical of fatty acid.

Fatty acids radical are non-polar, but presence of carboxyl group in molecule stipulates strong polarity of complex esters. Such structure of biocomponents provides their surface activity and thus, ability to form boundary film.

Basing on these data we may assume that increasing of biocomponent content in blends causes increasing of surfactants quantity and as the result strengthening of boundary film between friction pair.

Another property that influences on details wear is fuel viscosity [20, 25]. Conventional jet fuels with lower viscosity are composed of compounds with smaller molar mass. Their molecules have smaller sizes and thus smaller dipole moment. As a result, the boundary film formed at the solid surface possesses less strength comparing to fuels with higher viscosity values. Except that, decreasing of molecules' size causes increase of average speed of their chaotic heat movement and promotes destruction (desorption) of the boundary film.

In order to verify theoretical data about viscosity influence on lubricating properties, the kinematic viscosity of investigated fuel blends was measured. Because the lubricity properties of jet fuel blends were tested at temperature 60 °C, the kinematic viscosity ν_{60} was measured at the same temperature regime. The measurement results are presented in Table 1.

From Table 1 we can see that kinematic viscosity of conventional oil-derived jet fuel is much lower comparing to viscosity of biocomponents. Such high values of FAME viscosity are explained by their chemical structure. Viscous characteristics of conventional jet fuel depends on their hydrocarbon composition: content of alkanes (paraffin's), cycloalkanes (naphthens), mono- and bicyclic arenes with average number of carbon atoms in molecule from 5 to 16. At the same time, hydrocarbon chain of ester molecules contain about 14–23 carbon atoms [26, 27]. This influences on molecules' size and thus decreases the speed of their chaotic movement. It is clearly seen from the table 1 that increasing of biocomponent content in blends causes increasing of their viscosity. Fig. 16 depicts the dependence of viscosity and scuffing load increment with increasing of biocomponents content in fuel blends.

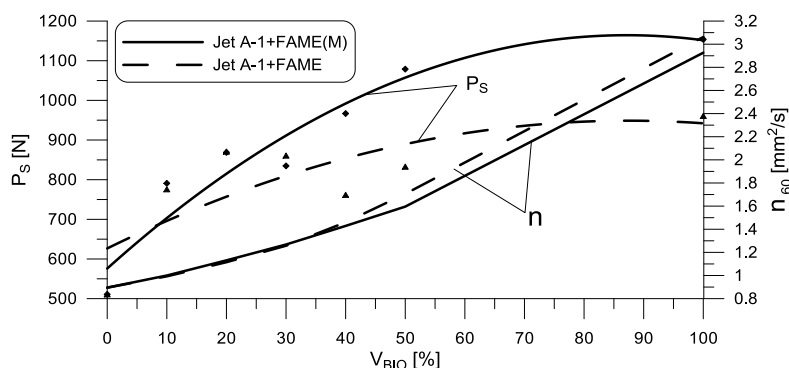


Fig. 16. Friction pair scuffing load P_s , fuel viscosity ν as a function of biocomponent content in fuel blends

Fig. 16 shows the dependence between friction pair scuffing load and fuel viscosity. Increasing of fuel viscosity causes strengthening of boundary film at the surface of the friction pair; it results in increasing of scuffing load. Thus, the obtained results prove that antiwear properties of jet fuels directly are connected with fuel viscosity that provides wearing surfaces division by liquid layer; and presence of surfactants in fuel that form high strength absorption layer at the wearing surfaces that provides decreasing of friction coefficient and details wearing.

Table 1

Kinematic viscosity of tested fuel samples

Sample name	Viscosity at 60 °C, mm ² /s	Sample name	Viscosity at 60 °C, mm ² /s
JFA1	0,89500	JFA1	0,89500
JFA1-B10	0,99289	JFA1-B10M	0,99992
JFA1-B20	1,11510	JFA1-B20M	1,13090
JFA1-B30	1,25760	JFA1-B30M	1,26790
JFA1-B40	1,46030	JFA1-B40M	1,42880
JFA1-B50	1,70560	JFA1-B50M	1,59570
B100	3,06220	B100M	2,92630

7. Conclusion

A four-ball tester with a facility for a continuous load increase was used for estimation lubricity properties of conventional jet fuel and its blends with rape oil derived biocomponents. The comparative tests of fuel blends indicated that rape oil FAME exhibit better permanent boundary film creation properties comparing to, conventional jet fuel within the scope of the tested friction pair.

This effect is explained by surface activity of FAME molecules and its high viscosity. The results of the tests have shown that increasing of biocomponent content in fuel blend caused strengthening of boundary film of friction pair surface.

It may be assumed that alternative jet fuels, which contain rape oil derived biocomponent are characterized by better antiwear properties. Other words, rape oil esters positively affect lubricity properties of conventional jet fuels and may be used

as an improver of jet fuel antiwear properties. The use of rape oil esters may have a number of advantages. Among them: substitution of conventional oil with renewable resource, decreasing of exhaust gases emissions toxicity, improvement of safety parameters of fuel, decreasing of carbon dioxide emissions.

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References

1. Kandaramath Hari, T. Aviation biofuel from renewable resources: Routes, opportunities and challenges [Text] / T. Kandaramath Hari, Z. Yaakob, N. N. Binitha // Renewable and Sustainable Energy Reviews. – 2015. – Vol. 42. – P. 1234–1244. doi: 10.1016/j.rser.2014.10.095
2. Maurice, L. Q. Advanced aviation fuels: a look ahead via a historical perspective [Text] / L. Q. Maurice, H. Lander, T. Edwards, W. E. Harrison // Fuel. 2001. – Vol. 80, Issue 5. – P. 747–756. doi: 10.1016/s0016-2361(00)00142-3

3. Liu, G. Technical review on jet fuel production [Text] / G. Liu, B. Yan, G. Chen // *Renewable and Sustainable Energy Reviews*. – 2013. – Vol. 25. – P. 59–70. doi: 10.1016/j.rser.2013.03.025
4. Hileman, J. I. Alternative jet fuel feasibility [Text] / J. I. Hileman, R. W. Stratton // *Transport Policy*. – 2014. – Vol. 34. – P. 52–62. doi: 10.1016/j.tranpol.2014.02.018
5. Jenkins, R.W. Potential renewable oxygenated biofuels for the aviation and road transport sectors [Text] / R. W. Jenkins, M. Munro, S. N. Christopher, C. Chuck // *Fuel*. – 2013. – Vol. 103. – P. 593–599. doi: 10.1016/j.fuel.2012.08.019
6. Honga, T. D. A study on developing aviation biofuel for the Tropics: Production process – Experimental and theoretical evaluation of their blends with fossil kerosene [Text] / T. D. Honga, T. H. Soerawidjajab, I. K. Reksowardojo, O. Fujitac, Z. Duniani, M. X. Phame // *Chemical Engineering and Processing: Process Intensification*. – 2013. – Vol. 74. – P. 124–130. doi: 10.1016/j.cep.2013.09.013
7. Chuck, C. J. The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene [Text] / C. J. Chuck, J. Donnelly // *Applied Energy*. – 2014. – Vol. 118. – P. 83–91. doi: 10.1016/j.apenergy.2013.12.019
8. Lapuerta, M. Properties of fatty acid glycerol formal ester (FAGE) for use as a component in blends for diesel engines [Text] / M. Lapuerta, J. Rodriguez-Fernandez, C. Estevez, N. Bayarri // *Biomass and bioenergy*. – 2015. – Vol. 76. – P. 130–140. doi: 10.1016/j.biombioe.2015.03.008
9. Alves, S. M. Tribological behavior of vegetable oil-based lubricants with nanoparticles of oxides in boundary lubrication conditions [Text] / S. M. Alves, B. S. Barros, M. F. Trajano, K. S. B. Ribeiro, E. Moura // *Tribology International*. – 2013. – Vol. 65. – P. 28–36. doi: 10.1016/j.triboint.2013.03.027
10. Method of jet fuels component production from plant feedstock. Patent of Ukraine No 95751 [Text] / Iakovlieva A. V., Boichenko S. V., Vovk O. O. – Registered on 12.01.2015.
11. Kallio, P. Renewable jet fuel [Text] / P. Kallio, A. Pasztor, M. K. Akhtar, P. R. Jones // *Current Opinion in Biotechnology*. – 2014. – Vol. 26. – P. 50–55. doi: 10.1016/j.copbio.2013.09.006
12. Hu, J. Study on the lubrication properties of biodiesel as fuel lubricity enhancers [Text] / J. Hu, Z. Du, C. Li, E. Min // *Fuel*. – 2005. – Vol. 84. – P. 1601–1606. doi: 10.1016/j.fuel.2005.02.009
13. Maru, M. M. The Stribeck curve as a suitable characterization method of the lubricity of biodiesel and diesel blends [Text] / M. M. Maru, R. M. Trommer, K. F. Cavalcanti, E. S. Figueiredo, R. F. Silva, C. A. Achete // *Energy*. – 2014. – Vol. 69. – P. 673–681. doi: 10.1016/j.energy.2014.03.063
14. Xu, Y. Characterization of the lubricity of bio-oil/diesel fuel blends by high frequency reciprocating test rig [Text] / Y. Xu, Q. Wang, X. Hu, C. Li, X. Zhu // *Energy*. – 2010. – Vol. 35, Issue 1. – P. 283–287. doi: 10.1016/j.energy.2009.09.020
15. Devyanin, S. N. masla i topliva dlya dizelnykh dvigatelei [Text] / S. N. Devyanin, V. A. Markov, V. G. Semenov. – Kh.: Novoe Slovo: 2007. – 423 p.
16. Agarwal, S. Tribological behavior of diesel fuels and the effect of anti-wear additives [Text] / S. Agarwal, V. K. Chhibber, A. K. Bhatnagar // *Fuel*. – 2013. – Vol. 106. – P. 21–29. doi: 10.1016/j.fuel.2012.10.060
17. Geller, D. P. Effects of specific fatty acid methyl esters on diesel fuel lubricity [Text] / D. P. Geller, J. W. Goodrum // *Fuel*. – 2004. – Vol. 83, Issue 17–18. – P. 2351–2356. doi: 10.1016/j.fuel.2004.06.004
18. Aviation Turbine Fuel Lubricity – A Review [Text]. – CRC Report AV-14-11. Coordinating Research Council, Inc., 2014.
19. Yanovskii, L. Inzhenernyye osnovy aviatsionnoi khimologii [Text] / L. Yanovskii, N. Dubovkin, F. Galimov. – Kazan: Izdatelstvo Kazanskogo Universiteta, 2005. – 367 p.
20. Dubovkin N. Inzhenernyye metody analiza fiziko-khimicheskikh i ekspluatatsionnykh svoystv topliv : monografiya [Text] / N. Dubovkin, L. Yanovskiy, T. Shigabaev, F. Galimov, V. Ivanov. – Kazan: Master-line, 2000. – 378 p.
21. T-02U. Aparat czterokulowy – instrukcja obsługi [Text]. – Radom: Wydawnictwo Instytutu Technologii Eksploatacji, 2011.
22. Szczerek, M. Tribological researches – scuffing [Text] / M. Szczerek, W. Tuszycki. – Radom: Institute for Sustainable Technologies – National Research Institute, 2000.
23. Piliavskiy, V. Improvement of lubricating properties of ethanol motor fuels [Text] / V. Piliavskiy, E. Polunkin, O. Gaidai // *Proceedings of the 2-d All-Ukrainian ecological conference, 2013*. – P. 46–50.
24. Anastopoulos, G. HFRR lubricity response of an additized aviation kerosene in CI engines [Text] / G. Anastopoulos, E. Lois, F. Zannikos, S. Kalligeros, C. Teas // *Tribology International*. – 2002. – Vol. 35, Issue 9. – P. 599–604. doi: 10.1016/s0301-679x(02)00050-6
25. Yanovskii, L. S. Osnovy aviatsionnoi khimologii : uchebnoie posobie [Text] / L. S. Yanovskii et al. – Moscow: Izdatelstvo MATI, 2005. – 678 p.
26. Nagornov, S. A. Tekhnika i tekhnologii proizvodstva i pererabotki rastitelnykh masel [Text]: uchebnoie posobie / S. A. Nagornov, D. S. Dvorecky, S. V. Romancova, V. P. Tarov. – Tanbov: Izdatelstvo TGTU, 2010. – 96 p.
27. Sarin, R. Biodiesel surrogates: Achieving performance demands [Text] / R. Sarin, R. Kumar, B. Srivastav, S. K. Puri, D. K. Tuli, R. K. Malhotra, A. Kumar // *Bioresource Technology*. – 2009. – Vol. 100, Issue 12. – P. 3022–3028. doi: 10.1016/j.biortech.2009.01.032