22-osios jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“ teminės konferencijos
TRANSPORTO INŽINERIJA IR VADYBA,
vykusios 2019 m. lapkričio 22-23 d. Vilniuje, straipsnių rinkinys

Proceedings of the 22th Conference for Junior Researchers 'Science – Future of Lithuania'
TRANSPORT ENGINEERING AND MANAGEMENT, 22-23 November 2019, Vilnius, Lithuania

Сборник статей 22-й конференции молодых ученых «Наука – будущее Литвы»
ИНЖЕНЕРИЯ ТРАНСПОРТА И ОРГАНИЗАЦИЯ ПЕРЕВОЗОК, 22-23 ноябрь 2019 г., Вильнюс, Литва

INVESTIGATION OF ANTI-WEAR PROPERTIES OF MIXED AVIATION FUELS BASED ON ETHYL ESTERS OF CAMELINA OIL

Serhii Ternovenko
National Aviation University, Kyiv Kosmonavt Komarov, ave. 1, 03058 Kyiv, Ukraine,
E-mail: sergeyka929@gmail.com

Abstract: Presented studies are related to the spheres of aviation and machine-building. Anti-wear properties of conventional jet fuel, fatty acids ethyl esters bio-additives derived from camelina oil and their blends were investigated experimentally. It was found that lubricity of bio-additive is significantly higher comparing to conventional oil-derived jet fuel. It was found that addition of bio-additive into the composition of jet fuel leads to strengthening of boundary film, decreasing of friction coefficient and improvement of anti-wear properties of fuel blends. The mechanism of fatty acids esters influence on improvement of anti-wear properties of jet fuel was substantiated. It was shown that camelina oil fatty acids esters positively influence on lubricating ability of oil-derived jet fuels and may be used in order to improve anti-wear properties of conventional jet fuels.

Keywords: jet fuels, alternative fuels, biodiesel, anti-wear properties, tribology, friction, aviation fuel supply.

Introduction

The studies described in this article are related to the aviation fuel supply and aircraft operations.

World aviation technology experience has accumulated a huge amount of statistical material on the failure of airborne systems due to the increased level of parts wear. Generalized experience on the operational reliability of domestic and foreign aircraft fuel systems indicates that almost 30% of all accidents and catastrophes, up to 50% of aircraft engine failures, 20 to 40% of hydraulic and nearly 10% of fuel systems failures are due to a decrease in the performance of fuels, and for this reason the life of pumps and other units is reduced by 6-7 times (Vasilieva 2016, Shaabdiev 2017).

Formulation of the problem. The purpose and objectives of the study

The reliability of fuel and hydraulic units in aviation technology depends largely on the performance of precision friction pairs. Increased wear, fracture, and jamming of friction pairs cause failure of the hydraulic units, and there is a need to replace the worn parts systematically. The most common defects are: jamming of plunger, plate and spool pairs, destruction of rolling bearings, wear of plunger bearings and so on. The specificity of these friction pairs requires a critical approach to the question of using existing ideas about the relative influence of lubricants, the mechanical properties of materials, the roughness of conjugated surfaces, the speed of their relative movement.

Today in the world, much attention is paid to alternative energy sources, in particular, alternative fuels. But in most cases, it's fuel for cars. Given the rapid growth of the fleet and the large volumes of refueling per aircraft, the issue of alternative fuels for aviation engines remains relevant. Particular attention should be paid to investigating the performance of such fuels as they have a direct impact on flight safety. In the works (Chuck 2014, Hu 2005) it is established that alternative fuels for air-jet engines, obtained from the vegetable base are characterized by low lubricating properties, in comparison with aviation fuels of petroleum origin. At the same time, there are reports of fairly good lubricating properties of vegetable oil esters (Nagornov 2005, Yakovleva 2017).

Taking into account the known data on the lubricating properties of vegetable oil esters, it is of interest to study their effect on the wear properties of fuels for gas turbine engines.

The purpose of this work was to investigate the anti-wear properties of mixed vegetable-mineral fuels for air-jet engines containing ethyl esters of red oil. Accordingly, one of the objectives of the study was to compare the anti-wear properties of these mixed fuels with the anti-wear properties of mineral fuels for gas turbine engines.

The work was carried out within the framework of scientific topic 182DB18 "Improving the performance of fuels for gas turbine engines, safety of aviation transport and its environmental friendliness".

The object of the study was to improve the anti-wear properties of blended aviation fuels containing ethyl esters of red oil.

The subject of the study was the modified vegetable base aviation fuels and the influence of ethyl esters of fatty acids of red oil on the regularities of formation of tribotechnical characteristics of mixed aviation fuels.

Experiment and data processing

It is known that the anti-wear properties of the fuel for the AJE determine the reliability and the life of the fuel units of aviation systems, in particular their friction pairs (Hu 2005, Nagornov 2005, Yakovleva 2017). These pairs operate in rolling, sliding, and combined friction modes at different loads, temperatures, pressure, and relative motion speeds under liquid and extreme lubrication conditions.

The lubricating properties of fuels depend on their chemical composition, viscosity, thermo-oxidative stability, the content of mechanical impurities, the presence of surfactants (Sirenko 2008). At high specific loads, semi-liquid friction is usually observed when the friction surfaces are not completely separated by fuel. In the case of semi-liquid friction, the antiwear properties of the fuel for the AJE are determined by the viscosity of the fuel, which provides the hydrodynamic effect of separating the friction surfaces with a layer of liquid, as well as the presence of surfactants in the fuel, which form a high strength absorption layer which separates the surfaces of friction and thereby reduces the coefficient of friction and wear coefficient of the parts (Dubovkin 2002).

The analysis of literature sources (Bratkov 1987) shows the authors' interest in experimental and theoretical development of increasing the wear properties of precision friction pairs and studies of the influence on the wear properties of different components of fuels and oils. One of the directions of prolonging the life and restoration of tribounits is tribomodification of the friction surfaces due to the formation of stable oxide films by the use of modified or energy-modified lubricants.

During the experiment, the anti-wear properties of aviation fuel JET A-1, ethyl ester of fatty acid of camelina oil and mixtures of JET A-1 with vegetable biocomponents were investigated. The JET A-1 brand met the requirements of ASTM D1655 (An American National Standard ASTM D1655). The bio-additives components were presented with a mixture of camelina oil fatty acids ethyl esters (EEFA (M)), meeting the requirements of EN 14214 (Liquid petroleum products), specially modified for use as a component of fuels for AJE. The modification was carried out by vacuum fractionation in accordance with the developed technology (Patent No. 95751 Ukr.). Samples of fuel mixtures contained these bio-additives in an amount of 10, 20, 30, 40 and 50%.

Typically, the anti-wear properties of fuels for the AJE are estimated by the amount of wear of the characteristic friction pair. Wear in the environment of a particular fuel of one arbitrary pair of friction cannot characterize the lubricating properties of this fuel uniquely. Changing the material of parts, test modes and other factors can significantly affect the wear of the friction surfaces. In this regard, the evaluation of anti-wear properties is carried out under strictly regulated conditions (Svirid 2006).

To investigate the condition of the friction surfaces and the coefficient of friction, a complex was used to study the tribological characteristics of fuel and lubricants developed by the authors (Svirid 2006). For the study of materials for friction and wear, the installation for investigation of materials for friction and wear during reversing movement (Fig. 1), developed by the authors, was used (Patent No. 70877 Ukr. 2012).

Fig. 1. Installation for investigation of materials for friction and wear during reversing movement: 1 – independent power supply; 2 – ammeter for magnetic field registration; 3 – ammeter for recording current in the friction zone; 4 – breaker; 5 – magnetic core; 6 – inductance coil; 7 – power supply; 8 – an oscilloscope for registration of parameters of electric current in a magnetic circuit; 9 – load; 10 – node friction; 11 – capacity for the working environment.

The studies were carried out according to the scheme of friction "finger-plane", material of samples ШХ15 - steel 45 (hardened to the value of HRC 52), ϑ = 0,20; P = 5 H, frequency = 1 Hz. Dimensions of the finger-sample: diameter – 4 mm, length – 25 mm. The deterioration of the specimens was performed by profiling the wear spots and obtaining the amount of volumetric wear according to the method (Trofimov 2011). The length of friction of all samples was 8 km.

Tests on the friction machine were carried out in the lubricating media of the following tests: No. 1 – JET A-1; No. 2 – ethyl ester of fatty acid of camelina oil (EEFA); No. 3 – JET A-1+ camelina oil EEFA 20%; No. 4 – JET A-1+ camelina oil EEFA 30%; No. 5 – JET A-1+ camelina oil EEFA 40%; No. 6 – JET A-1+ camelina oil EEFA 50%. The results of the experiment are presented in the Table 1.

Table 1. Tribotechnical characteristics of a pair of friction ШХ15 – steel 45 in different lubricants (samples No. 1-6) at T = 353 K.

Samples	μ (coefficient of friction)	I_V, mm³
1	2	3
No. 1	0.4	0.08
No. 2	0.35	0.0044
No. 3	0.3	0.006
No. 4	0.3	0.0035
No. 5	0.35	0.0022
No. 6	0.35	0.0026

Fig. 2 shows micrographs of friction surfaces. The studies were carried out on a complex for investigation of the anti-wear properties of fuel and lubricants by the method described in this work (Svirid 2006).

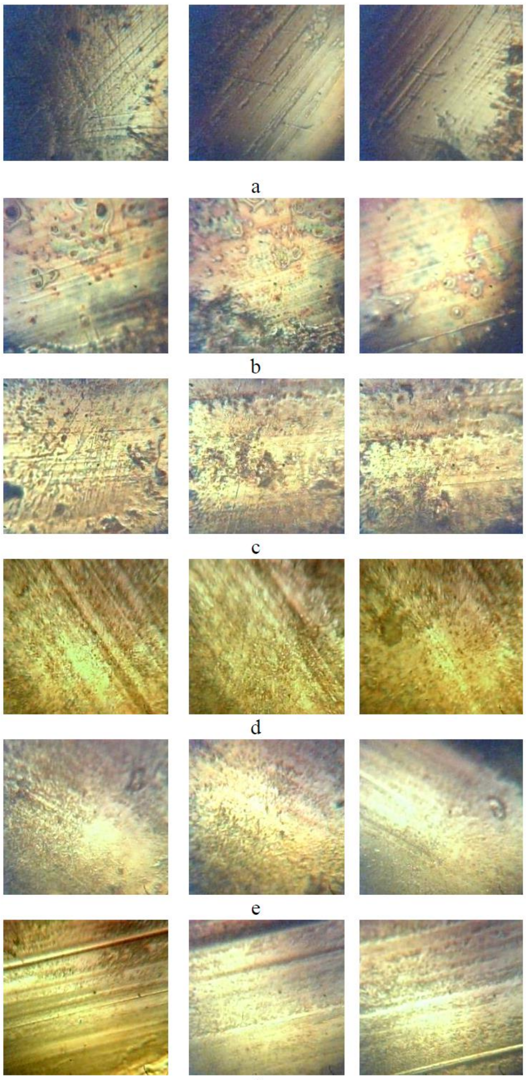

Fig. 2. Microphotographs of friction surfaces (increased by 400 times): *a* – development in the environment JET A-1; *b* – development in the environment of 100% camelina oil EHF; *c* – the development in the environment JET A-1 + camelina oil EEFA 20%; *d* – the development in the environment JET A-1 + camelina oil EEFA 30%; *e* – development in the environment JET A-1 + camelina oil EEFA 40%; *f* – the development in the environment JET A-1 + camelina oil EEFA 50%.

Comparing the friction surfaces, it can be argued that the friction surfaces of the specimens which were spent in camelina oil EEFA (Fig. 2*b*) are more uniform than the friction surfaces of the basic JET A-1 (Fig. 2*a*) and the oxide films are thinner and more elastic. This completely explains the lower value of the coefficient of friction and the amount of wear in the same friction path. Moreover, in Fig. 2*b* contours of the oxide films are clearly visible. As they are mixed in different proportions of blended fuels, the sample films become much larger in length and width than the sample films produced in EEFA red oil, and their contrasting color makes it possible to state that the films of the sample surface are rubbed against the sample. Fig. 2*b* have a smaller thickness and are more elastic. Fig. 2*d* clearly shows that the friction surfaces have become uniform over the entire stain of wear, the oxide films are smaller in size, but concentrated tightly over the entire surface. This completely explains the decrease in the amount of wear for the samples produced in 30% and 40% of JET A-1 + EEFA mixtures. Fig. 2*f* shows that the friction surface becomes smoother compared to the friction surfaces in Fig. 2*d* and Fig. 2*e*, but the oxide films are displaced and the micro-irregularities increase. This completely explains the slight increase in the amount of wear and the coefficient of friction.

The effect of reducing the amount of wear when camelina oil fatty acid esters added to jet fuel can be explained by the fact that the esters increase the polarity, and therefore the adsorption capacity of the ether molecules and the shift of electron density to the oxygen atoms of the carbonyl group. It is also worth noting that known fact that the strength of ester-based films is up to 22,000 kg/cm^2, while for mineral oils is about 4,500 kg/cm^2 and for synthetic oils is about 9,000-12,000 kg/cm^2. In this work, by adding esters to the JET A-1 base jet fuel, we have obtained: the strengthening of an oil film on the friction surface; increasing the grafting of metal surfaces; an additive in the form of fatty acids, included in the esters.

Conclusions

Studies of blend fuel samples have shown that the ethyl esters of camelina oil fatty acids present the ability to form a stronger boundary film on friction surfaces compared to fuels for air-jet engines of petroleum origin. This ability is explained by the surface activity of ester molecules and their high viscosity. Taking the JET A-1 fuel sample as a control, we can conclude that the use of red oil esters has a positive effect on the lubricating properties of air-jet engines.

It has been determined that the fatty acid esters of red oil have a positive effect on the lubricity of petroleum fuels for air-jet engines and can be used to improve the anti-wear properties of traditional aviation fuels.

References

An American National Standard ASTM D1655 Standard Specification for Aviation Turbine Fuel. − https://global.ihs.com/doc_detail.cfm?document_name=ASTM%20D1655&item_s_key=00015939

Bratkov, A.; Seregin, E.; Gorenkov, A. 1987 *Khimmotologia raketnyh i reaktivnyh topliv*. 304 p.

Chuck, C. J.; Donnelly, J. 2014. The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene. Applied Energy. Vol. 118. pp. 83–91.

Dubovkin, N.; Yanovskiy, S. 2002. *Inzhenerniye metody opredeleniya fiziko-khimicheskih i ekspluatacionnyh svoistv topliv.* Kazan: Kazanskiy nauchny centr, Otdel energetiki, Rossiyskaya inzhenernaya akademiya bibliografii. 365-376 p. (Rus).

Hu, J., Du, Z., Li, C., Min, E. 2005. Study on the lubrication properties of biodiesel as fuel lubricity enhancers. Fuel. Vol. 84. pp. 1601–1606.

Liquid petroleum products — Fatty acid methyl esters (FAME) for use in diesel engines and heating applications — Requirements and test methods. − https://infostore.saiglobal.com/preview/98708742874.pdf?sku=861350_SAIG_NSAI_NSAI_2049227

Nagornov, S.; Dvoretskii, D.; Romantsova, S.; Tarov V. 2010. *Teknika i tekhnologii proizvodstva i pererabotki rastitelnyh masel.* Tambov: Izdatelstvo GOU VPO TGTU 96 p. (Rus) ISBN 978-5-8265-0964-7.

Patent № 70877 Ukr., MPK G 01 N 3/56 Svirid M.,; Kravets I.; Priymak L.; Borodiy V. Prystriy dlya doslidzhennya poverkhon tertya. № u201115161. Zayavleno 21.12.2011. Opublikovano 25.06.2012, Byul. № 12.

Patent № 95751 Ukr., MPK C10L 10/00/ Yakovleva, A.; Boichenko, S.; Vovk, O. Sposib otrymannya komponenta palyv dlya povitryano-reaktyvnyh dvyguniv iz syrovyny roslynnogo pohhodzhennya № u201406122. Zayavleno 04.06.2014. Opublikovano 12.01.2015 Byul. № 1.

Shaabdiev, S. 2017. Analiz nadezhnosti toplivnoi sistemy regionalnogo pasagirskogo samoleta AN-140 na nachalnom etape expluatacii. Voprosy proektirovaniya i proizvodstva konstrukciy letatelnyh aparatov 3:83-89 (Rus) – http://nbuv.gov.ua/UJRN/Pptvk

Sirenko, G.; Midak, L.; Kuzyshyn, O.; Kirichenko, L.; Kirichenko, V. 2008. Antifrikciyni vlastyvosti polikomponentnyh kompoziciy na osnovi khimichno modifikovanoi ripakovoi olyvy pid chas maschennya pary aromatychny poliamid. *Stal'. Polimer. Journal*. 30:338-344 (Ukr)

Svirid, M.; Paraschanov, V.; Onischenko. A. 2006. *Kompleks dlya doslidzhennya trybotekhnichnyh parametriv vuzla tertya. Problemy tertya ta znoshuvannya*. 45:204-209

Trofimov, I.; Burykin, V.; Zakharchuk, V. 2011. Doslidzhennya protyznosnyh vlastyvostey palyv, obroblenyh elektrychnym polem, za skhemoyu tribokontaktu "tsylindr – ploschina". *Porodorazrushayuschiy i metaloobrabatyvayushchiy instrument: tekhnika i tekhnologiya ego izgotovleniya i primeneniya.* 14:602-608

Vasilieva, T. 2016. Prognozirovanie pokazatieley nadyozhnosti avitsionnoy tekhniki s ispolzovaniem ryadov Furye. *Nauchno-metodicheskiy electronnyy journal "Concept"* 15:1476-1480 (Rus) — URL: http://e-koncept.ru/2016/96214.htm

Yakovleva, A.; Vovk, O.; Boichenko, S.; Lejda, K.; Kuszewski, H. 2017. Physical-chemical properties of jet fuels blends with components derived from rapeseed oil // *Journal of Chemistry & Chemical Technology.* – Vol. 10. – No. 1. – P. 485-492. doi.org/10.23939/chcht10.04.485