STUDY OF LOW-TEMPERATURE PROPERTIES OF AVIATION BIOFUELS

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Introduction

The jet fuel Jet A/Jet A-1, the product used in today's airliners, has been largely refined from crude oil feedstock. In recent times, however, the aviation industry became aware of emissions and its contribution to climate change. It has also raised concerns over future supply security and operational costs. These factors have led to interest in the development of product produced from alternative sources.

Advancement in process technology is providing alternative means of producing traditionally distilled crude products, through the conversion of coal, gas or biomass. The processing techniques provide production of fuels, which have similar properties to conventional Jet A-1 fuel.

Literature overview

The promising feedstock for alternative JFs production is plant biomass (corn, rapeseed, soybean, camelina, algae, etc), animal fats, industrial, household and municipal waste, etc [1]. Today, one of the main tasks in the field of production and use of alternative aviation fuels and lubricants is meeting a number of requirements related to efficiency, reliability and durability of transport vehicles [2].

During previous studies the samples of new alternative JFs were developed and first lab test of its physical chemical properties were fulfilled [3, 4]. This kind of alternative JF is a mixture of conventional JF of grade Jet A-1 and bio-additives produced from plants oil up to 50 %. New fuels were obtained using bio-additives produced from rapeseed oil (RO). It is known that today rapeseed is one of the promising types of feedstock within the European region [5, 6].

At the same time it is well-known that one of the key operational parameters of JF is its low temperature properties. These properties determine aircraft reliable and sable operation at wide range of conditions and thus provide flight safety that is a main principle of modern civil aviation. Today much works are devoted to the question of studying low-temperature properties of alternative JF [7].

Purpose of this study is to investigate the basic low-temperature properties of alternative aviation fuels, and to determine how they correspond to the norms of traditional aviation fuels and to what extent they can replace them. *Objectives* of the study are: to measure parameters of such properties of fuels as a viscosity and freezing point (FP), to construct diagrams basing on the results of the research.

Requirements to low-temperature properties of jet fuels

Low-temperature properties of JFs are characterized by its behaviour at low temperatures and are strictly controlled by specifications. During exploitation JFs usually have to work at very low temperatures, especially in winter and during high-altitude flights at altitudes of 9–12 km, where temperature reaches -50–-70 °C (Kulik et. al, 2015).

Cooling of JFs may be accompanied with clogging of fuel filters that may be associated with aircrafts accidents and disasters. Cooling of fuel also affects reduction of spraying efficiency by fuel nozzles and worsening fuel pumps operation.

Low-temperature properties of fuels are characterized by physical and chemical phenomena, which occur in fuels at temperatures below 0 °C. At low temperatures insoluble precipitates of organic nature appear and affect the operation of the fuel system. The main reasons for their occurrence are sharp decrease of some fuel components solubility with a temperature decrease and phase transitions. The main source of low-temperature precipitate in JFs is the crystallization of fuel's hydrocarbons when FP is reached. Decreasing of temperature causes crystallization of hydrocarbons, rise of crystals concentration and fuel gradually loses its fluidity and then freezes. When reaching pour point (PP) the complete turbidity of fuel is observed. More cooling results in fuel solidification.

Description of equipment and experiment realization

Within the scope of this study, low-temperature properties of JFs blended with bio-additives were estimated by PP, FP and kinematic viscosity at low temperatures. For fulfilling experimental studies conventional JF of grade Jet A-1, that meets requirements of specifications, was used.

For obtaining blended JFs three types of bio-additives were used:

– Fatty acids methyl esters (FAME) of Rom whuch quality parameters meet requirements of specifications;
– FAME of RO that were specially modified by vacuum distillation according to the method described in [8];
– Fatty acids ethyl esters (FAEE) of RO that were also modified according to the mentioned method.

Within the scope of this work we have studied low-temperature properties of pure JF, pure samples of bio-additives and JF blends, which contained 10 %, 20 %, 30 %, 40 % and 50 % of each type of bio-additives.

Bio-additives based on FAME and FAEE of RO are characterized by higher values of PP comparing to conventional JF (Table 1.). High values of bio-additives PP are stipulated by chemical structure of molecules and by Van der Waals interactions between them. The length of the hydrocarbons chain (C_{15}–C_{25}) defines the large size of the compounds and due to this binding energy between molecules is higher comparing to conventional JFs.

Table 1

PP of JF and bio-additives samples

Designation of fuel sample	**Pour point, °C**
Jet fuel of grade Jet A-1	- 59.0
FAME of rapeseed oil	- 15.0
Modified FAME of rapeseed oil	- 19.0
Modified FAEE of rapeseed oil	- 18.5

Due to the existence of forces of intermolecular interaction the speed of random motion of esters molecules is insignificant. With a decrease of temperature its association grows fast: on the one hand, because of decrease in thermal motion of molecules, which weakens the bonds between them, and on the other – because of decrease in mobility of esters molecules, which are "bounded" with each other. Further temperature decrease causes viscosity rise to such a degree that esters freeze and loose its mobility.

The experimental results have shown that blending JFs with bio-additives increased its PP. The dependence of fuels' PP on bio-additive concentration was built (Fig. 1).

When concentrations of bio-additives are less than 30% (v/v), their effect on the FP is relatively insignificant. At low concentrations they are uniformly distributed in the volume of JF and distances between esters' molecules are not enough for interaction appearance. Further increase of esters content causes rise of PP that gradually approaches to values typical for pure esters.

When content of bio-additives in JF exceeds 30 % the amount of comparatively large esters molecules is sufficient for their associations. Thus, associated esters' molecules initiate formation of structure within blended JFs. The other explanation of PP of blended JFs rise may be proposed: during temperature decrease small molecules of JF bond with associated esters molecules. This promotes association of hydrocarbons and freezing of blended JFs.

We have also assumed that with temperature decrease there is a certain phenomenon in modified fuels: small-sized molecules of hydrocarbon fuel are combined with individual molecules or a set of associated esters molecules, which promotes the association of hydrocarbons and its hardening [5].

It is known that the reason for the decreasing of fuel pumpability at low temperatures is a significant increase in fuels' viscosity [9]. In order to evaluate viscosity of blended JFs we have determined fuels viscosity in temperature range from -20 to 100 ^{o}C. Then we have studied the mutual influence of temperature t and concentration c of bio-additives on its viscosity ν (Fig. 2–4.). This was done by the method of linear regressive analysis.

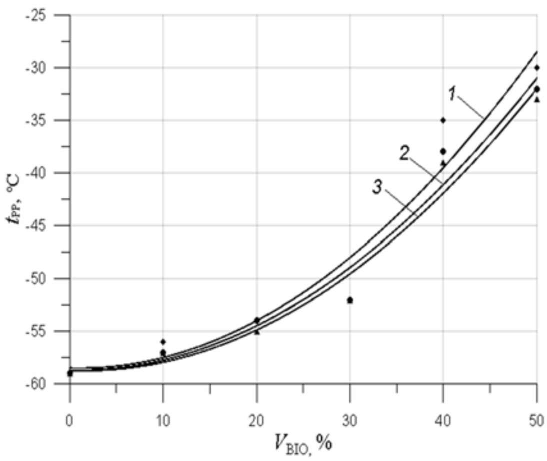

Fig. 1. Dependence of fuels' PP on bio-additive concentration: 1 – jet fuel + FAME, 2 – jet fuel + modified FAME, 3 – jet fuel + modified FAEE

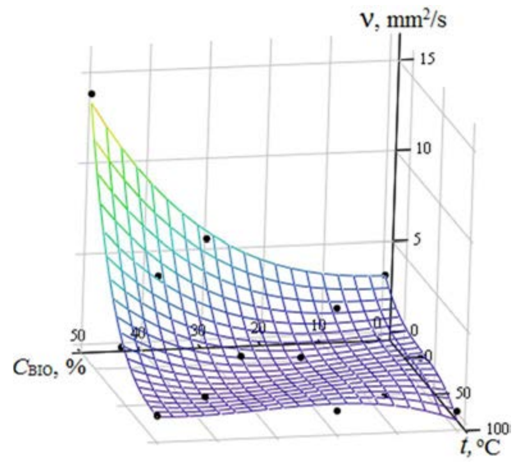

Fig. 2. Kinematic viscosity of tested fuel samples as a function of temperature and FAME bio-additive concentration.

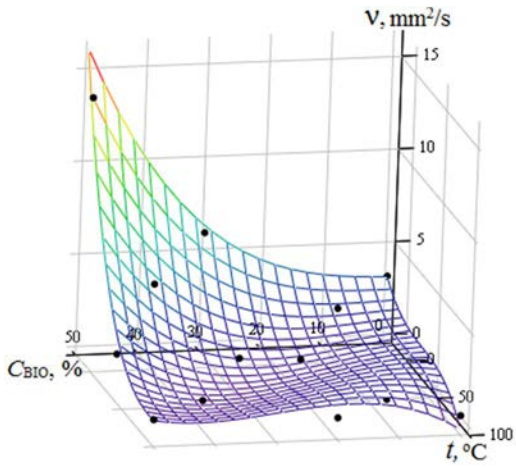

Fig. 3. Kinematic viscosity of tested fuel samples as a function of temperature and modified FAME bio-additive concentration.

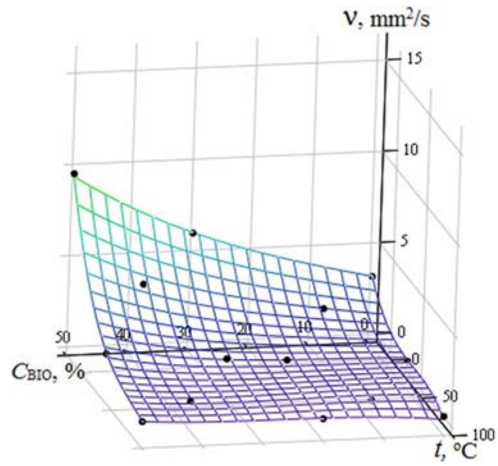

Fig. 4. Kinematic viscosity of tested fuel samples as a function of temperature and modified FAEE bio-additive concentration.

Thus, increasing the concentration of esters and reduction of the temperature are factors that contribute to the association of molecules of blended JFs primarily due to increasing the number of collisions (contacts) of esters' molecules. And reduction of temperature is a factor that strengthens the ties associated molecules by reducing the speed of molecules thermal motion and, consequently, increases the viscosity and PP. Results on fig 2 – 4 show both, the influence of individual factors (temperature and bio-additives concentration) and also their mutual influence.

It is known that the dependence curves of the viscosity of JFs on its temperature change in the low temperature zone rather rapidly. These 3D models show that even insignificant increase of temperature causes a significant decrease in fuels' viscosity. To avoid potential problems with blended JFs spraying at low temperatures it is possible to increase fuel pressure before the nozzles. This technical solution is well-known for a long time and has been successfully used during JEs exploitation [5].

Conclusion

In a result of the work the complex of low-temperature properties of the new alternative jet fuels were studied. Experimental results have shown that rising the content of bio-additives in conventional JF leads to general worsening of low-temperature properties of JFs that is revealed by rising of FP. This factor limits using of bio-additives in JFs' blends: thus maximal content of bio-additives may be 30 % (v/v). JFs' blends of such composition completely satisfy requirements of specifications to conventional JFs. According to modern specifications maximal FP of jet fuels shouldn't be higher that minus 47 ^{o}C.

It was concluded that maximal content of bio-additives in alternative JFs is 30 % (v/v). Taking into account insignificant difference in characteristics of JFs blended with methyl and ethyl esters it is more rational to use rather FAEE than FAME. The use of ethanol provides production of bio-additives of completely renewable feedstock.

References

[1] Abu-Taieh, C.; Evon, J. 2011. *Technology Engineering and Management in Aviation: Advancements and Discoveries*. Information Science Reference.

[2] Iakovlieva, A.; Boichenko, S.; Vovk, O. *J. of Chem. and Chem. Techn.*, 2013, 3, 305.

[3] Chuck, C.; Donnelly, J.: *Applied Energy*, 2014, 118, 83.

[4] Hileman, J.; Stratton, R.: *Transport Policy*, 2014, 34, 52.

[5] Yanovskii, L., Dmitrenko, V., Dubovkin, N. et. al. Osnovy aviatsionnoi khimmotologii.:MATI, Moscow, 2005.

[6] Yakovleva, A.; Boichenko, S.; Leida, K.; Vovk, O.; Kuzhevskii, Kh.: Chem. and Techn. of Fuels and Oils, 2017, 53(3), 308.

[7] Pankin, K., Ivanova, Ju., Kuzmina, R., Stykov, S. Chem. and Techn. of Fuels and Oils, 2011, 2, 23.

[8] Iakovlieva, A.; Boichenko, S.; Lejda, K.; Vovk, O.; Shkilniuk I.: *Proceedia Engineering*, 2017, 187, 363.

[9] Kulik, N., Aksenov,A., Yanovskii, L.: Aviatsionnaya himmotologiya topliva dlia aivatsionnyh dvigatelei. Teoreticheskiie i inzhenerniie osnovy promeneniya. 2015, NAU, Kyiv, 557 p