Experimental Study of Rape Oil Esters Influence on Physical-Chemical Properties of Jet Fuels

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Abstract. The work is devoted to the development of alternative jet fuel blended with rape oil-derived biocomponents and studying their physical-chemical properties. The modification of conventional jet fuel by rape oil esters was chosen for this work among the variety of technologies for alternative jet fuels development. The main characteristics of conventional jet fuel and three kinds of biocomponents were determined and compared to the standards requirements to jet fuel of grade Jet A-1. The most important or identifying physical-chemical properties of jet fuels was determined for the scope of this study. Among them are: density, viscosity, fractional composition, freezing temperature. The influence of rape oil-derived biocomponents on the mentioned above characteristics of blended jet fuels was studied and explained. The need in study of exploitation properties of new alternative jet fuels was substantiated.

Keywords: jet fuel, alternative fuel, biocomponent, rape oil, physical-chemical properties, density, viscosity, fractional composition, freezing temperature.

Introduction

Constant increase of aircraft fleet and exhausting crude oil deposits promote worsening of the world energy crisis. As a result we observe rise in prices for jet fuel that today comprise about 25–30 % of passenger travel. Moreover, products of fuel combustion cause detrimental impact on environment (Hileman 2014). Thus, the task of search and development of alternative jet fuels became especially important.

This work is devoted to the study of possibilities of partial replacement of conventional jet fuels with component of biological (plant) origin. It will allow decreasing of dependence on exhaustible energy sources and minimizing negative impact of aviation on environment.

Today alternative fuels from various renewable feedstock are actively developed and studied. Among them are fuels made of biomass, plant oils, animal fats, microalgae, waste from agriculture, wood processing industry, municipal waste etc (Iakovlieva et al. 2013). Thus, jet fuels produced from biomass via FT-synthesis and hydration of fats were successfully tested (Chuck 2014). There is also good experience in use of aviation biokerosene that is a mixture of conventional jet fuel and biocomponents produced from plants oil up to 50 %. For many reasons today this kind of alternative jet fuels is the most perspective for Ukraine. And the most rational feedstock is rape or camellina oils (Boichenko 2012).

The purpose of this work is to study the influence of biocomponents derived from rape oil on physical-chemical properties of jet fuel and analysis of their influence on exploitation characteristics of jet fuels.

Requirements to jet fuels and production of biocomponents

Today there are strict requirements to jet fuels connected with efficiency, reliability durability of aircraft equipment and environmental safety (Boichenko 2012). This complex of requirements is provided by physical-chemical, exploitation and ecological properties of jet fuels, which are determined by nature and properties of raw material, methods of basic fractions productions, methods of their purification and mixing, additives applied.

As it is known, conventional jet fuels are produced from middle-distilled oil fractions with boiling temperatures 140–280 °C (ligroin-kerosene, gasoline-kerosene and gasoil fractions). They are obtained via direct distillation of low-sulfur and sulfur oils (Yanovskii et al. 2005). Biocomponents, used for modification of jet fuels, are...
fatty acids esters produced by esterification of plant oils. Usually methanol or ethanol are used for esterification. The use of ethanol is more preferable as it is less toxic and derived from plant feedstock. As a result biocomponents are completely made of renewable raw materials and seem to be environmentally safe (Iakovlieva et al. 2014).

The first step of our work was studying of physical-chemical properties of conventional jet fuel Jet A-1 and tree kinds of biocomponents. Experimental studies were done for fatty acids methyl esters (FAME) of rape oil and also fatty acids methyl (FAME(M)) and ethyl (FAEE(M)) esters of rape oil specially modified for use in jet fuels. The modification was done by vacuum distillation (Iakovlieva et al. 2014). It allows achieving higher level of biocomponents purification and improvement of physical-chemical properties. Characteristics that are the most important for comparing conventional jet fuel and biocomponents are presented in Table 1.

As we can see, properties of biocomponents differ from properties of conventional jet fuels. The next step in our work was to study the influence of biocomponents on physical chemical properties of blended jet fuel according to the following characteristics: density, fractional composition, viscosity and freezing temperature.

**Study of the influence of biocomponents on physical chemical properties of blended jet fuels**

Density and fractional composition directly influence on fuel volatility – processes of evaporation, fuel-air mixture formation, completeness of combustion, net fuel flow, absence of smoke and soot in combustion chamber. Density plays an important role for estimation fuel energy properties, mainly heat value (Wcislo 2013).

Viscosity causes impact on fuel pumpability in aircraft fuelling system: determines injection and spraying of fuel in combustion chamber. Viscosity influences on fuel filters and nozzles efficiency at low temperatures, mainly degree of fuel spraying and droplets diameter. Increased viscosity causes worsening of fuel vaporizability and completeness of combustion. At the same time viscosity stipulates anti-wear properties of jet fuels (Iakovlieva et al. 2015).

Freezing point allows estimating low-temperature properties of jet fuels, mainly fluidity at low temperatures during high-altitude flights of sub-sonic aircrafts.

**Density of fuel samples was estimated using device for density and concentration determination “Anton Paar”, DMA 4500M according to the standard ASTM D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter. Methyl and ethyl esters of rape oil are characterized by significantly high values of density comparing to conventional jet fuels. It is explained by the chemical structure of esters. Hydrocarbon chains of esters contain 14–26 carbon atoms on average, on the contrary to conventional jet fuel that contains only 5–16 carbon atoms. It causes high values of esters' molecular mass and thus their density. Fig. 1 shows that increasing of biocomponent content in samples of blended fuels causes increasing of their density.**

**Fractional composition of fuel samples was determined using automatical fractional composition analyzer “Herzog Optidist” according to the standard D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure. As it is known conventional jet fuel is a mixture of hydrocarbons of different structure. Due to this they do not have a defined boiling temperature rather evaporate in a wide range of temperatures. At the same time biocomponents are also a mixture of organic compounds. They belong to the class of aliphatic fatty acids esters and differ from each other by geometric structure, molecular mass and thus boiling temperature. Boiling temperatures of esters significantly differ from fractional composition of conventional jet fuels and do not coincide with them (Wcislo 2013).**

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM D1655</th>
<th>Jet fuel Jet A-1</th>
<th>FAME</th>
<th>FAME(M)</th>
<th>FAEE(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at temperature 15 °C, kg/m³</td>
<td>775–840</td>
<td>794.03</td>
<td>882.92</td>
<td>883.68</td>
<td>876.58</td>
</tr>
<tr>
<td>Fractional composition °C:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– 10 % distilled at temperature, max</td>
<td>max 205</td>
<td>169.15</td>
<td>334.91</td>
<td>327.23</td>
<td>336.69</td>
</tr>
<tr>
<td>– 50 % distilled at temperature, max</td>
<td>registered</td>
<td>186.2</td>
<td>336.99</td>
<td>334.78</td>
<td>337.2</td>
</tr>
<tr>
<td>– 90 % distilled at temperature, max</td>
<td>registered</td>
<td>217.13</td>
<td>347.09</td>
<td>343.35</td>
<td>336.14</td>
</tr>
<tr>
<td>– end of distillation, max</td>
<td>300</td>
<td>243.44</td>
<td>354.50</td>
<td>348.95</td>
<td>274.4</td>
</tr>
<tr>
<td>Kinematic viscosity, mm²/s:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– at minus 20 °C, max</td>
<td>8.0</td>
<td>3.2923</td>
<td>16.05 (-5)</td>
<td>14.656 (-5)</td>
<td>17.886 (-8)</td>
</tr>
<tr>
<td>Freezing point, °C, max</td>
<td>minus 47</td>
<td>minus 57</td>
<td>minus 15</td>
<td>minus 19</td>
<td>minus 18.5</td>
</tr>
<tr>
<td>Flash point, °C, min</td>
<td>38</td>
<td>43</td>
<td>130</td>
<td>167</td>
<td>170</td>
</tr>
<tr>
<td>Content of aromatics, % (mas.), max</td>
<td>22</td>
<td>17.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lower heat of combustion, MJ/kg, min</td>
<td>42.8</td>
<td>43.218</td>
<td>37.315</td>
<td>37.131</td>
<td>37.550</td>
</tr>
</tbody>
</table>

Fig. 1. Dependence of blended jet fuels density on the content of biocomponents: 1 – jet fuel Jet A-1 + FAME, 2 – jet fuel Jet A-1 + FAME(M), 3 – jet fuel Jet A-1 + FAEE(M)
Boiling temperatures of biocomponents are within a very narrow range; moreover the most part of the volume (about 75–80 %) boils even in more narrow range – about 20–25 °C. It is explained by that fact that about 80 % of studied biocomponents belongs to esters of oleic, linoleic, and linolenic acids. Significant decrease of final boiling point of FAEE up to 274 °C may be explained by its chemical destruction. Presence in FAEE molecules of additional methyl group increases their molecular weight (comparing to FAME) and thus boiling temperature that higher than temperature of molecules thermal destruction.

Study of fractional composition of blended jet fuels has shown that addition of fatty acids esters to jet fuels causes widening of their fractional composition mainly the final boiling point (Fig. 2–4).

**Fig. 2.** Fractional composition of 1 – fuel Jet A-1, 2 – fuel Jet A-1 + 10 % of FAME, 3 – fuel Jet A-1 + 20 % of FAME, 4 – fuel Jet A-1 + 30 % of FAME, 5 – fuel Jet A-1 + 40 % of FAME, 6 – fuel Jet A-1 + 50 % of FAME, 7 – FAME

**Fig. 3.** Fractional composition of 1 – fuel Jet A-1, 2 – fuel Jet A-1+10 % of FAME(M), 3 – fuel Jet A-1+20 % of FAME(M), 4 – fuel Jet A-1+30 % of FAME(M), 5 – fuel Jet A-1+40 % of FAME(M), 6 – fuel Jet A-1+50 % of FAME(M), 7 – FAME(M)

**Fig. 4.** Fractional composition of 1 – fuel Jet A-1, 2 – fuel Jet A-1 + 10 % of FAEE(M), 3 – fuel Jet A-1 + 20 % of FAEE(M), 4 – fuel Jet A-1 + 30 % of FAEE(M), 5 – fuel Jet A-1 + 40 % of FAEE(M), 6 – fuel Jet A-1 + 50 % of FAEE(M), 7 – FAEE(M)

Fractional composition curves mean that boiling temperature ranges of conventional jet fuels and fatty acids esters do no coincide even partially. Increasing of biocomponent content on each 10 % causes output of high boiling fractions respectively.

Addition of biocomponents to jet fuel may negatively influence on completeness of combustion and soot formation from one side. But from another side decreasing of light boiling fractions content may decrease it evaporability. This will allow decreasing of fuels losses from evaporation, minimizing possibility of vapor locks formation and increasing of fuel fire safety. At the same time it may improve energy content of jet fuel.

**Viscosity** of fuel samples was determined using automatic device for viscosity determination “Herzog Low temperature viscometer”, HVU 482 according to the standard ASTM D445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity). Biocomponents made of FAME and FAEE of rape oil have significantly higher viscosity values comparing to conventional jet fuel. The reason of this is length of hydrocarbon chain that determines the big size of compounds. Due to this the speed of chaotic molecules’ movement decreases and as a result viscosity increases. Except that, about 80 % of biocomponents is esters of unsaturated fatty acids with one or two double bonds. Due to the presence of double bonds esters’ molecules take curved-shape form that additionally increases their viscosity. Viscous-temperature characteristics of conventional jet fuel and biocomponents sample are shown at Fig. 5.

We can easily see that esters viscosity depends on temperature more strongly comparing to conventional jet fuel.

Addition of biocomponents to jet fuel causes increasing of blended fuels viscosity that is shown on Fig. 6.

It may negatively influence on fuel pumpability through the aircraft fuelling system, mainly decrease
productivity of fuel pumps and quality of fuel spraying. At the same time increased viscosity positively influence on antiwear properties of jet fuels (Iakovlieva et al. 2015).

Fig. 5. Influence of temperature on viscosity:
1 – fuel Jet A-1, 2 – FAME, 3 – FAME(M), 4 – FAEE(M)

Fig. 6. Dependence of blended jet fuels viscosity on the content of biocomponents: 1 – jet fuel Jet A-1 + FAME, 2 – jet fuel Jet A-1 + FAME(M), 3 – jet fuel Jet A-1 + FAEE(M)

Freezing temperature of fuel samples was determined using device for low-temperature properties determination “UTF” according to the standard GOST 5066-91 (ISO 3013-74) Motor fuels. Methods of determination of cloud point and freezing point (method B). Biocomponents are characterized by significantly high values of freezing temperature comparing to conventional jet fuel. Length of esters’ molecules stipulates their high viscosity and its dependence on temperature. Due to the molecules’ size their mobility is low (comparing to jet fuels). When temperature decreases, association between molecules quickly rises: due to the depression of heat motion from one side and reduction of heat motion between molecules from another side. When temperature continues decreasing esters cool down and completely loose their mobility. Fig. 7 describes the rise of freezing point of blended fuels with increasing content of esters.

Fig. 7. Dependence of blended jet fuels freezing temperature on the content of biocomponents: 1 – jet fuel Jet A-1 + FAME, 2 – jet fuel Jet A-1 + FAME(M), 3 – jet fuel Jet A-1 + FAEE(M)

Studying the influence of biocomponents on freezing temperature of jet fuels we determined that up to 30 % (vol.) of esters in jet fuel blends doesn’t influence on temperature essentially. But with increasing of biocomponents content freezing temperature starts rising approaching values typical for pure esters.

Thus we may predict that blended jet fuel with esters additives will possess increased freezing temperature. It may negatively influence on aircraft’s fuelling system operation, mainly fuel pumpability at low temperature. So, the content of biocomponent in blended jet fuel shouldn’t exceed 30 % (vol.).

Conclusion

In a result of the work the complex of physical-chemical properties and quality parameters of jet fuel and rape oil esters were studied. The results have shown that the main characteristics of biocomponents differ from conventional jet fuels.

The dependencies of jet fuel density, fractional composition, viscosity and freezing temperature on the content of biocomponents were obtained. It was determined that jet fuel modification by biocomponents will have controversial effect on exploitation properties of new fuels. On one hand it may negatively influence on combustion process, and on the other hand it allows improving certain exploitation characteristics and making new jet fuel more environmentally clean.

It may be concluded that modification of conventional jet fuel by rape oil-derived components is possible. At the same time there is a need in more detailed influence of biocomponents on fuel properties for optimization of jet engines operation using new kind of fuel.
References


