21-osios jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“ teminės konferencijos
**TRANSPORTO INŽINERIJA IR VADYBA**,
vykusios 2018 m. gegužės 4-5 d. Vilniuje, straipsnių rinkinys

Proceedings of the 21th Conference for Junior Researchers 'Science – Future of Lithuania'
**TRANSPORT ENGINEERING AND MANAGEMENT**, 4-5 May 2018, Vilnius, Lithuania

Сборник статей 21-й конференции молодых ученых «Наука – будущее Литвы»
**ИНЖЕНЕРИЯ ТРАНСПОРТА И ОРГАНИЗАЦИЯ ПЕРЕВОЗОК**, 4-5 мая 2018 г., Вильнюс, Литва

# COMPARATIVE CHARACTERISTICS OF BIOCOMPONENTS BASED ON RAPESEED AND CAMELLINA OILS FOR BLENDING WITH JET FUELS

**Vladyslav Stadnichenko**

*National Aviation University, Department of Ecology, Kyiv, Ukraine*
*E-mail: stadal01@gmail.com*

**Abstract.** This manuscript is devoted to the biofuels based on rapeseed and camellina oils components and studying their characteristics. Also here are the results of comparisons presented biofuels with the traditional Jet A-1 fuel. The main characteristics of Jet biofuels based on oils components were compared with standard requirements of Jet fuels. Such physical-chemical properties were determined in this work: density, fractional composition, viscosity, freezing point, flash point, content of aromatics, heat of combustion and the test on copperplate was occurred.

**Keywords:** biofuel, jet fuel, oil component, physical-chemical properties, density, viscosity, freezing point, flash point.

## Introduction

Today application of alternative energy sources in various spheres of human activity becomes more and more popular all over the world and in Eastern European countries as well. Along with development and implementation of alternative motor fuels, scientists around the world study perspectives of partial or total substitution of traditional jet fuels with their alternative analogues. Following the world tendencies we see the need to consider potential in development and application of alternative jet fuels produced from plant oils. The analysis was done for Eastern Europe countries.

## Literature overview

Modern civil aviation is developing constantly. The world volume of aircraft transportation increases on 4–5 % annually. As a result during last decade consumption of fuels for air-jet engines has increased on 21 %. As it is stated in (Iakovlieva 2015) about 5.5 thousand barrels of jet fuel is produced and consumed in the world daily.

Today aviation is one of the most significant consumers of oil-derived jet fuels. Oil and other fossil fuels used for production both jet and other kinds of fuels are exhausted irreversible. Oil deposits are estimated at about 40 years, natural gas – 70 and coal – 230 years. $CO_2$ emissions accompanying processes of fuel production and use, stipulate increase of greenhouse effect, and therefore global warming on the plane (Thushara 2015). Intergovernmental Panel on Climate Change and International Energy Agency (IEA) state that modern aviation is a source of about 2% of the world's total $CO_2$ emissions (Fig. 1).

Such rapid increase of $CO_2$ in the atmosphere is connected to active development of the aviation industry. According to the forecasts the number of aircrafts will increase in two times till 2031 and will count about 31 thousand units. Enlargement of air fleet and number of flights consequently leads to increasing jet fuels consumption. During the 10 year period (1992÷2002) the level of jet fuel consumption has risen by 21 %. Besides $CO_2$ aircraft exhaust gases contain number of other components that negatively influence on the state of environment: $SO_x$, $NO_x$, CO, $CH_4$, soot, and others (Iakovlieva 2013).

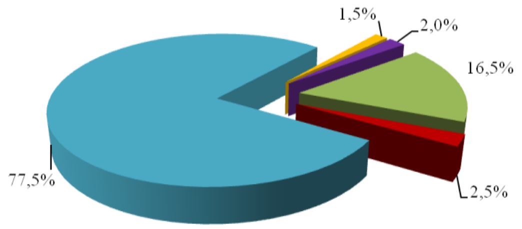


**Fig. 1.** The share of $CO_2$ emissions from air transport comparing to other kind of transport: 1.5 % – international aviation, 2 % – international marine transport, 16.5 % – motor transport, 2.5 % – other kinds of transport, 77.5 % – other energy sources

Quantitative and qualitative composition of aircrafts emissions determines ecological properties of jet fuels.

Mostly they depend on the content of heteroatom compounds and aromatics in fuel. Other words, ecological properties of jet fuels and respectively aircraft's emissions are determined by the quality of crude-oil (Thushara 2015). Except that we should mention that amount of greenhouse gases formation during jet fuel production from natural gas is in 1.8 times lower and from coal is in 2.4 times higher comparing to crude-oil. Processing of bituminous coal is accompanied with $CH_4$ emission that is also one of the greenhouse gases. At the same time $SO_x$ emissions are absent during combustion of fuel made of natural gas. Such situation promoted strengthening of ecological requirements to quality of jet fuels. Number of influential organizations took measures on prevention of aviation negative impact on environment. International Air Transport Association (IATA) has set up the task to reduce the level of $CO_2$ emissions from air transport by 50% by 2050. In addition, European Commission in 2011 has set a policy target of achieving a 60 % reduction of $CO_2$ by 2050. Low-carbon fuels in aviation should reach 40 % by 2050. Besides, European Committee insist on using about 4% of fuel produced from plant feedstock in aviation. In future this may help to step forward in achieving the goal to cut down $CO_2$ emissions. According to the experts' forecast the use of jet biofuels can guarantee 80% reduction of $CO_2$ emissions comparing to conventional aviation fuel (Hileman 2014)

Thus, we can see that the search in methods and technologies of alternative jet fuels production from renewable feedstock was acknowledged as a key direction for solving such questions as energy and resource saving and environmental protection in aviation.

## Modern situation in sphere of jet fuels production

Traditionally fuels for jet engines are produced from crude oil, coal, natural gas, oil sands and oil-shales. However, technologies are quite energy-intensive and difficult for realization. Limitation of the world's oil deposits and other fossil fuels promotes development of alternative technologies for jet fuels production. Today numbers of organizations pay much attention to investigation of existing and newly appeared technologies for alternative jet fuels production. Scientists define jet fuels derived from: conventional oil, unconventional oil (oil sands and oil shale), natural gas, coal, or biomass via the FT-process, renewable oils (biodiesel, biokerosene, hydroprocessed renewable jet or Hydrotreated Vegetable Oil – HVO) and alcohols (ethanol and buthanol). However, alcohol-derived fuels are suitable for aviation piston engines only (Hileman 2014). The most perspective are fuels derived from plant feedstock– the so called biofuels. IEA forecasts the share of biofuels in total balance of fuel in transport sector will reach 4–6 % till 2030 (Kinder 2009).

Development and use of jet biofuels contributes to the appropriate legal regulation. Implementation guidelines strictly define certain types of biofuels in the consumer market. Today areas used for biofuels crops cultivation in Europe are more than 2,500 hectares. Basically these crops are cereals and rape seed. At present, the 13.2 hectares of EU lands are available for cultivation of biofuel cultures. Till 2020 this area may increase up to 20.5 hectares, and till 2030 – to 26.2 hectares. According to the European Commission, in order to achieve the 2020 goal for energy crops it is necessary to use 17.5 hectares or about 10 % of agricultural lands used in the EU countries.

Biofuel holds a special place in the structure of renewable energy sources. Being one of the few alternative fuels in the transport sector, biofuels are seen as an important resource in the choice of energy sources and ensuring of energy security, development of agriculture and rural, as well as to mitigate climate change by reducing greenhouse gas emissions.

The formal classification of energy crops to the appropriate categories (Fig. 2) has been published in a report titled Biofuels in the European Vision, Vision 2030 and Beyond. According to these reports biofuels are divided into the first and the second generation biofuel. Department of Transport and Energy of the European Commission has figured out a third generation biofuel. The third generation fuel, known as a future fuel may be obtained from oils produced from micro- and macroalgae (Lebedevas 2006). Conditionally biomass as feedstock for biofuels production can be divided into three generations. Currently there are following generation of biofuels:

– edible oil and sacchariferous terrestrial plants;
– inedible cellulosic plants;
– inedible aquatic plants, i.e. algae.

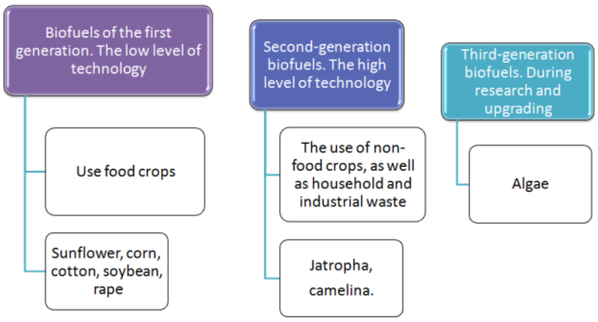


**Fig. 2.** Classification of biofuels according to generations

Biofuel of first generation made from sugar, starch, vegetable oil and animal fat using conventional technology. The main sources of raw materials are the seeds or grain. For example, from rapeseed extract vegetable oil, which can then be used as biodiesel. From wheat obtained starch, after fermentation – bioethanol (Firrisa 2013).

Deforestation, negative impact on traditional agriculture, the imbalance of agricultural land use in the direction of industrial crops and the threat of the food security - these are some of the problems facing humanity during production of biofuels. The main problem in the production of fuel from biomass is food security, because first-generation biofuels made from agricultural crops entering in the food chain of humans and animals (corn, soybeans, palm oil, rape, sugarcane, wheat, rye). The public has thought suddenly that large areas where food was produced, commercially oriented farmers was given to the technical culture. Because the world population grows and requires more and more food, the use of these areas for the production of biofuels reduces the amount of available food and increases their prime cost. Second-generation biofuels produced from non-food raw materials. Sources of raw materials are lignocellulosic compounds the remaining after, as suitable for use in the food industry part of vegetable raw materials are removed. For this purpose, also can be used fast-growing trees and grasses (poplar, willow, miscanthus, jatropha). They are called energy forests or plantations. Tested about 20 different species of plants – arboreal, shrubs and herbaceous.

In September 2013, the European Parliament decided to reduce the share of first-generation biofuels in total biofuel balance because of its environmental load. It is easy to consider, when the yield of a crop like rape is 30 kg/ha, then it is possible to obtain 1.0–1.3 tons of oil per hectare. It means that about 9 million hectares of arable land was used for cultivation of technical culture. At the same time 45–80 kg of nitrogen, 18–40 kg of phosphorus, 25–100 kg of potassium, 30–150 kg of calcium, 5–15 kg of magnesium, 30–45 kg of sulfur were taken out from the soil during production 1 ton of seeds. So, we can easily conclude that production of biofuel crops depletes the fertile layer of soil of 2 cm thick that was formed over 100 years. The production of renewable raw materials for biofuels without scientific justification leads to depletion of the soil and reducing crop yields, raw material for biofuels deterioration, water and soil pollution by agrochemicals and fertilizers (Kinder 2009).

During last years, we observe criticism of first-generation biofuels because the fuel produced from rapeseed and similar crops is not effective for reducing $CO_2$ emissions. The proportion of first-generation biofuels in transport fuel balance according to the decision of the European Parliament should be reduced to 5.5 %. In addition, after 2020, the EU may completely abandon the first-generation biofuels.

## Feedstock base for jet biofuels production

Feedstock for biocomponents production is oils, obtained from seeds of various agricultural oily plants: rape, sunflower, camellina, jatropha, canola, palm oil, etc. (Firrisa 2013). The main factor for feedstock selection is surely geographical and climatic conditions typical for country-producer and optimal for certain oily plant cultivation (Hileman 2014). Base of European biofuel industry is rape and during last years – camellina. Ukraine is traditionally agricultural country with well-developed oil production branch. The most typical oil cultures in Ukraine are sunflower, rape, soy; camellina and corn are less popular (Fig. 3).

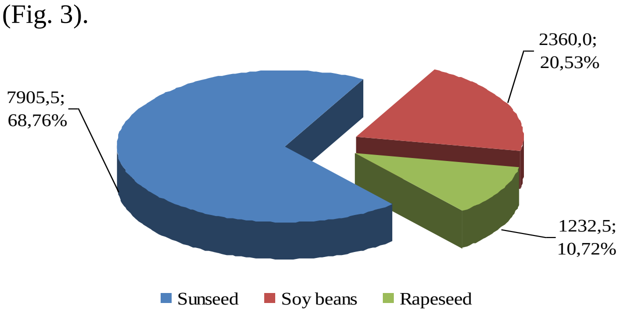


**Fig. 3.** Production of main oily plants in Ukraine in 2012 (thousand ton)

## Physico-chemical properties of fuels for jet engines and biocomponents based on camelina and rapeseed oils

The leading role in ensuring the reliability and efficiency of the jet engines and the corresponding aircraft is played by fuel quality. Modern aviation fuels must comply with requirements for efficiency, ecological properties, reliability and durability of aircraft.

**Table 1.** Physical-chemical properties of jet fuel and biocomponents

| Property | ASTM D1655 | Jet fuel Jet A-1 | FAME of rapeseed oil | FAME of camelina oil |
|---|---|---|---|---|
| Density at temperature 15 ºC, kg/м$^3$ | 775 – 840 | 794,03 | 882,92 | 880 |
| Fractional composition ºC: | | | | |
| - 10% distilled at temperature, max | max 205 | 169,15 | 334,91 | 330,10 |
| - 50% distilled at temperature, max | registered | 186,2 | 336,99 | 333,27 |
| - 90% distilled at temperature, max | registered | 217,13 | 347,09 | 340,44 |
| - end of distillation, max | 300 | 243,44 | 354,50 | 351,12 |
| Kinematic viscosity, mm$^2$/s: | | | | |
| - at 20 ºC, max | - | 1,5004 | 7,2017 | 5,86 |
| Freezing point, ºC, max | minus 47 | minus 57 | minus 15 | minus 10 |
| Flash point, ºC, min | 38 | 43 | 130 | 124 |
| Content of aromatics, % (mas.), max | 22 | 17,5 | 0 | 0 |
| Lower heat of combustion, MJ/kg, min | 42,8 | 43,218 | 37,315 | 38,110 |
| Test on copper plate at 100 ºC for 3 h | 1 | 1 | 1 | 1 |

*The density of the fuel* for jet engines is one of its main physical characteristics; determined by the relation between mass of the fuel to the volume, that it occupies. Density directly impacts on the flammability of fuel – the processes of evaporation, mixing, complete of combustion, its specific consumption. The required density of fuel for jet engines ensures reliable of engine fuel system.

The density of the fuel for jet engines depends on its chemical and fractional composition. The increase of heavy fractions, aromatic hydrocarbons and reduction of paraffinic hydrocarbons contribute to increase the density of fuel (Iakovlieva *et al.* 2013).

The density of the fuel plays an important role in the evaluation of its energy properties, including energy and heat of combustion. Describing the flammability of fuel, typically use concepts of specific (mass) heat of combustion. Mass heat of combustion is determined by the chemical composition of fuel and increases with the relative number of hydrogen atoms in a molecule of hydrocarbons. Thus, among the components of fuel for jet engines had maximum heat of combustion are alkanes, then cyclanes, more aromatic hydrocarbons. Usually with increase of the boiling point the heat of combustion is reduced. Fuel for jet engines is a mixture of hydrocarbons of various structures, so not exactly defined boiling point and evaporate in a wide temperature range.

Biocomponents – fatty acids methyl esters (FAME) and fatty acids ethyl esters (FAEE) of Camelina oil – have considerably higher values of density compared to oil fuel for jet engines. Such density of esters values is predetermined by its chemical structure. Unlike petroleum hydrocarbon of fuels for jet engines, that containing from 5 to 16 carbon atoms, acyl radicals of ester molecules contain an average of 15-26 carbon atoms. Such length of esters molecules is the cause of the emergence of increasingly strong forces of dispersion interaction between them and, consequently, their higher density, compared with fuel for the jet engines.

The value of FAME density of Camelina oil and vacuum is 880 kg/m$^3$. And the value of density of Jet A-1 fuel is 795, when according to the specification for fuel of brand Jet A-1 it must be no less than 775 kg/m$^3$.

*Fractional composition of fuel* describes the content of fractions that boiling at certain temperature range. In accordance with the regulations is necessary to determine the initial boiling point, boiling dry of 10, 50, 90 and 98 % (vol.) or the end of the fuel boiling for jet engines fuels. These data allow evaluating the performance properties of the fuel and the fuel system: fuel evaporation, tendency to vapor lock, complete combustion of fuel, lack of smoke and carbon formation in combustion chamber (Iakovlieva *et al.* 2013).

Since the bio-components also is a mixture of organic compounds, for them are typical certain range of boiling points. They belong to another class of organic compounds that are different from petroleum hydrocarbons and with each other in structure, molecular weight and boiling point.

In chemmotology fractional composition is one of the main indicators, which characterize the volatility of fuels for jet engines. Volatility is one of the most important characteristics of the fuel, which determines their ability to move from liquid to vapor. Evaluation of fuels volatility for jet engines are carried out by indicators such as saturated vapor pressure and full heat of vaporization. Volatility affects on the boundaries of stable combustion, complete combustion and carbon formation.

Stable operation of the fuel at low temperatures for jet engines largely depends on the fluidity of fuels for the jet engines, which is measured by viscosity - a property of fluids to resist deformation of the volume by external forces. This resistance exists due to the forces of gravity between molecules of fuel. In general, the viscosity decreases with increasing of temperature and slightly increases with increasing of external pressure (Iakovlieva *et al.* 2013).

*The viscosity of fuels* is the average viscosity of all its components. The viscosity of fuels hydrocarbon for jet engines depends on the structure of molecules and their interactions, slightly on their molecular weight. Aromatic hydrocarbons have the highest viscosity, paraffin-naphthenic – the smallest. In accordance with the increase of the aromatic hydrocarbons content of the fuel viscosity for jet engines increases.

The viscosity directly impact on the pumpability of fuels on aircraft fuel system. Using of high-viscous fuels can cause reduce of productivity of booster fuel pumps, injection pressure reduction and quality of spraying. It is known that with increasing of fuels viscosity for jet engines pressure difference created by the booster pumps is reduced and power consumption of the engine increases.

Increasing of viscosity at the negative temperature impact on the work of fuel filter. And we know that the violation of their work is not due to high viscosity directly, but their ice crystals clogging or high melting hydrocarbons. Increasing the fuels viscosity at negative temperature effect on the work of fuel nozzles: reduced the degree of fuel dispersion, increased the size of the microdrops; This leads to the deterioration of volatility and completeness of combustion.

According to the specification for fuel of brand Jet A-1 kinematic viscosity must be not more than 1,25.

Mixture of fuel with bio-components based on FAME and FAEE of Camelina oil has much higher viscosity compared with petroleum fuels for jet engines. The reason, as noted above, is their chemical structure.

Too low values of viscosity of fuels for jet engines is also not desirable. Extremely thin atomization of fuel causes a local saturation of fuel-air mixture and, as a result, narrowing the range of stable operation of the combustion chamber. In addition, low viscosity adversely affect the anti-wear properties of fuels for jet engines.

*The flash point* of a volatile material is the lowest temperature at which vapors of the material will ignite, given an ignition source. The flash point is not to be confused with the autoignition temperature (the temperature at which the vapor ignites without an ignition source) or with the fire point (the lowest temperature at which the vapor will keep burning after having been ignited and the ignition source has been removed). The autoignition is higher than the flash point, because at the flash point the vapor may cease to burn when the ignition source is removed. Neither the flash point nor the fire point is dependent on the temperature of the ignition source, which is much higher.

*Freezing point of fuel* for jet engines characterize their behaviour at negative temperatures (Iakovlieva *et al.* 2013). These include are stringent requirements. This can be explained by the fact that the jet engines usually have to work at very low temperatures, especially in winter. In the summertime fuels are also can be very cooled in terms of high-altitude flight at subsonic jet airplanes. The reason for this is that the ambient temperature at an altitude of 9-12 km reaches to minus 50-70 °C. With cooling of fuels for jet engines disturbed normal operation of the fuel supply system. Most often this is expressed by clogging of fuel filters that may be associated with accidents and disasters.

With fuel cooling also reduced the efficiency of fuel spraying nozzles and worsening work of 105 fuel booster pump. From the different works know that filtering ability of fuels at low temperatures depends on the fractional composition, chemical composition and water content.

In general, low-temperature properties of fuels are characterized by complex physical and chemical phenomena that occur in them at temperatures lower than 0 °C. At low temperatures occur insoluble precipitates of organic nature that affect on the fuel system. The main reason for their occurrence is the sharp decline of fuel solubility of some of its components with decreasing of temperature and phase transitions. These sediments are a composition of amorphous and crystalline materials. To amorphous parts belong high-hetero organic compounds and salts of organic acids, to the crystal – hydrocarbons with a high crystallization temperature (Hileman 2014).

*The heat of combustion* is one of the most important physical and chemical parameters of fuel quality that characterizes its energy properties.

The main purpose during the use of fuel in the engine is to convert its chemical energy into heat for maximum heating of air that enters to the turbine and jet nozzle of aircraft. The process of heat release from the fuel occurs mainly in the combustion chamber. The main purpose of the fuel in the engine - providing the heat supply to air, to raise its temperature and increase its volume compared with the fact that it had after compression in the compressor. The larger the heated gas entering into turbine, the work of expansion is greater than the compression work. So, for the heating of required number of air and, consequently, obtaining the desired traction characteristics of engine appropriate to use the most energy-intensive fuel. It follows that the higher the calorific value of the fuel, the lower specific fuel consumption and more economic engine.

*Test on copper plate* is one of the main methods of fuels corrosion control for jet engines (Iakovlieva *et al.* 2015). The method consists in maintaining of copper plate among the fuel temperature of 100 °C for two hours and evaluating the degree of corrosion comparison with the reference sample.

Corrosion aggressiveness is an important performance characteristic of fuels for the jet engines. It affects on the durability and reliability of the jet engines. In terms of operation, often under the influence of fuel exposed to corrosion parts of the fuel system aggregates; influenced by products of burning fuel – aggregates of gas path of the engine. Corrosiveness is characterized by the presence of corrosion-aggressive of fuel components. These include sulfur and sulfur-containing compounds, the most aggressive of which are hydrogen sulfide and mercaptans. In addition, the reason of corrosive action of fuel for jet engines is oxygen hetero organic compounds, soluble acids and alkalis, dissolved oxygen, moisture and also insoluble moisture. The results showed that all samples withstand test on a copper plate.

## Conclusions

In this article I explored characteristics of Jet biofuels based on rapeseed and camellina oils components and compared them with the traditional Jet fuel and with the default values. First, I compared the densities of submitted fuels: the highest density at temperature 15 °C had biofuel based on rapeseed oil components (882.92 kg/м$^3$), biofuel based on camellina oil components took the second place and had 880 kg/м$^3$. Traditional Jet (794.03 kg/м$^3$) had more lower density. The default value of density is between 775 and 840 kg/м$^3$. Then I explored the fractional composition of fuels. Analyzed samples I discovered that biofuels based on rapeseed and camellina oils components had almost similar indicators of temperature, which were much higher than Jet A-1 indicators and default values. Analyzed kinematic viscosity at temperature 20 °C, I had concluded, that biofuel based on camellina oil components had higher viscosity (5.86 mm$^2$/s) in comparison with traditional Jet (1.5004 mm$^2$/s), but lower than in biofuel based on rapeseed oil components (7.2017 mm$^2$/s). Another situation with freezing point: biofuels based on oils components freezed on the temperature -10 ºC (camellina), -15 °C (rapeseed), but the default is -47 ºC. Traditional Jet was much better and had -57 ºC freezing point temperature. Biofuel based on rapeseed oil components had the highest temperature of flash point (130 ºC), a bit more than camellina biofuel (124 ºC) and approximately 3 times more higher than the default value (38 ºC) and traditional Jet (43 ºC). I noted, that this biofuels did not have aromatics, when the Jet A-1 had 17.5 % and the default value is about 22 %. Biofuels based on presented oils components had lower heat of combustion, than the default values. Traditional Jet had numbers that were close to normal. Test on copperplate at 100 ºC showed the similar results (1).

## References


Namrata Dangol, Dev S. Shrestha, James A. 2017. Duffield, Life-cycle energy, GHG and cost comparison of camelina-based biodiesel and biojet fuel, Biofuels.

Hileman, J.; Stratton, R. 2014. Alternative jet fuel feasibility. *Transport Policy.*

Thushara K. H.; Zahira Y.; Narayanan N. 2015. Aviation biofuel from renewable resources: Routes, opportunities and challenges, *Renewable and Sustainable Energy Reviews*.

Iakovlieva, A.; Boichenko, S.; Vovk, O. 2013. Overview of innovative technologies for aviation fuels production *Journal of Chemistry and chemical technology.*

Kinder J. D.; Rahmes T. 2009. Evaluation of Bio-Derived Synthetic Paraffinic Kerosene (Bio-SPK). *The Boeing Company Sustainable Biofuels Research&Technology Program*.

Lebedevas S., Vaicekauskas A. 2006. Research into the application of biodiesel in the transport sector of Lithuania. *Transport*. Vol. 21, Iss. 2, p. 80–87.

Iakovlieva A., Boichenko S., Vovk O., Lejda K. 2015. Potential of jet biofuels production and application in Ukraine and Poland. *International Journal of Sustainable Aviation*. Vol. 1. No.4, p. 314–323.

Firrisa M. T., Van Duren I., Voinov A. 2013. Energy efficiency for rapeseed biodiesel production in different farming systems. *Energy Efficiency.*