**Article citation info:**
Baczewski K, Szczawiński P. Investigation of the impact of a Jet A 1 aviation turbine fuel admixture on selected biodiesel properties and on its ageing process. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2017; 78(4): 117-128, http://dx.doi.org/10.14669/AM.VOL78.ART9

# INVESTIGATION OF THE IMPACT OF A JET A 1 AVIATION TURBINE FUEL ADMIXTURE ON SELECTED BIODIESEL PROPERTIES AND ON ITS AGEING PROCESS

# BADANIA WPŁYWU DOMIESZKI PALIWA LOTNICZEGO JET A-1 NA WYBRANE WŁAŚCIWOŚCI BODIESLA I PROCES JEGO STARZENIA

**KAZIMIERZ BACZEWSKI[1], PIOTR SZCZAWIŃSKI[2]**
Military University of Technology

## Summary

Results of investigation the impact of an admixture of the Jet A 1 aviation turbine fuel on the density, kinematic viscosity, acid number, and oxidation stability of rapeseed methyl esters (RME) have been presented. A growth in the Jet A 1 content of the biodiesel blend has been found to cause a reduction in the density, acid number, and kinematic viscosity of the blend and to raise its oxidation stability. These relations have been presented in the form of regression equations as functions of the Jet A 1 content in the blend, for this content varying from 0 % to 50 % by volume.

[1] Military University of Technology, Faculty of Mechanical Engineering; 00-908 Warszawa; ul. Witolda Urbanowicza 2, Poland; e-mail: kazimierz.baczewski@wat.edu.pl

[2] Military University of Technology, Faculty of Mechanical Engineering; 00-908 Warszawa; ul. Witolda Urbanowicza 2, Poland; e-mail: piotr.szczawinski@wat.edu.pl

Moreover, the impact of the access of air, sunlight, heat, and water on the characteristics of pure fuels and their blends was examined and the test results have been shown. It has been found that the adding of an admixture of the Jet A 1 aviation fuel reduces the intensity of RME ageing and that it may be one of the methods to improve the functional RME characteristics, including the oxidation stability of this fuel.

**Keywords:** biodiesel, aviation fuel, ageing, acid number, oxidation stability

## Streszczenie

Przedstawiono wyniki badań wpływu domieszki paliwa lotniczego Jet A-1 na gęstość, lepkość kinematyczną, liczbę kwasową i odporność na utlenianie estrów metylowych oleju rzepakowego (RME). Stwierdzono, że wraz ze wzrostem zawartości Jet A-1 w mieszaninie następuje zmniejszenie jej gęstości, liczby kwasowej, lepkości kinematycznej oraz wzrost jej odporności na utlenianie. Zależności te opisano równaniami regresji w funkcji zawartości paliwa Jet A-1 do 50% obj. w mieszaninie z biodieslem.

Ponadto podano wyniki badań wpływu dostępu powietrza, światła słonecznego, ciepła i wody na charakterystyki czystych paliw i ich mieszanin. Stwierdzono, że domieszka paliwa lotniczego Jet A-1 zmniejsza intensywność starzenia RME, a dodatek tego paliwa może być jedną z metod poprawienia charakterystyk funkcjonalnych RME, w tym jego odporności na utlenianie.

**Słowa kluczowe:** biodiesel, paliwo lotnicze, starzenie, liczba kwasowa, odporność na utlenianie

## 1. Introduction

Methyl esters of higher fatty acids (FAME, which stands for "fatty acid methyl esters"), popularly given a collective name "biodiesel", are now more and more widely used as a fuel for compression ignition (CI) engines. However, apart from numerous good points, including less harmful environmental impact, biodiesel has also some disadvantages, and those considered particularly important include ageing, i.e. changes in the chemical composition of this fuel during storage, handling, and use. The ageing of biodiesel is caused by e.g. its low oxidation stability, far lower than that of petroleum-derivative engine fuels (diesel fuels). The ageing, especially oxidation, of biodiesel causes deterioration in various characteristics of this fuel and the ageing products have a harmful impact on the fuel injection system and adversely affect the engine functioning.

The biodiesel ageing mechanisms, the factors that determine this process, the effects of ageing and oxidation, as well as the methods used to improve the biodiesel stability to ageing and oxidation were addressed in many research works and publications, e.g. [2, 5, 6].

One of the methods used to improve biodiesel characteristics, especially the ageing stbality, is the adding of diesel fuel obtained from crude oil processing to the biodiesel [4] (to make thus fuel blends). This is due to much higher oxidation stability of diesel fuel, resulting from the absence of unsaturated hydrocarbons and oxygen in the diesel fuel composition

as well as from very good miscibility of diesel fuel and biodiesel. The blends that contain up to 20 % (by volume) of biodiesel and not less than 80 % (by volume) of diesel fuel meet the standard requirements regarding the oxidation stability and no antioxidants have to be added to them [4].

Biodiesel also readily blends in any proportions with the aviation turbine fuel of the type of kerosene for turbine aircraft engines. The adding of the Jet A 1 aviation turbine fuel to rapeseed methyl esters (RME) considerably improves their low-temperature rheological properties [1, 3]. The characteristics of biodiesel and aviation fuel blends differ from those of individual blend components; they are not always additive to each other.

In terms of CI engine operation, the adding of aviation fuel to biodiesel may be expected to result in an increase in the calorific value and in a slight decline in the cetane number of the fuel. Engine tests [7] on blends of the JP 8 aviation fuel with biodiesel have shown that an admixture of the JP 8 fuel improves the performance characteristics of a CI engine and reduces the carbon monoxide, particulate matter, and hydrocarbon contents of the exhaust gases, with a slight increase in the nitrogen oxides content.

Aviation fuels show very good oxidation stability; hence, the adding of such fuels to biodiesel may be expected to raise the ageing stability of the mixture as well. To confirm such an expectation, tests were carried out to examine the impact of a Jet A 1 aviation fuel admixture on changes in selected biodiesel properties and on the biodiesel ageing stability.

## 2. Objective, program and scope of the tests

The tests were carried out to determine the impact of a Jet A 1 aviation turbine fuel admixture on selected biodiesel properties and on the biodiesel ageing stability, with rapeseed methyl ester (RME) being used as the biodiesel.

The scope of the tests covered:

- examination of the impact of the quantity of the Jet A 1 aviation turbine fuel added on the oxidation stability, density, kinematic viscosity, and acid number of the RME;
- exposure of samples of pure RME, Jet A 1 fuel, and their mixtures to the ageing process, i.e. to the action of atmospheric oxygen, sunlight, and water, in laboratory conditions for a period of 15 weeks;
- examination of the impact of the ageing process on the values of density, kinematic viscosity, and acid number of the fuels and their blends under test.

The tests were carried out on:

- pure rapeseed methyl ester with no improvers;
- commercially available Jet A 1 fuel for turbine aircraft engines.

Selected quality characteristics of both fuels have been specified in Table 1.

Table 1. Values of selected standard specifications of the fuels under test

| Description | RME | Jet A 1 |
|---|---|---|
| Density at a temperature of 15 °C [kg/m$^3$] | 883.5 | 796.0 |
| Kinematic viscosity | | |
| – at a temperature of 40 °C [mm$^2$/s] | 4.44 | 1.18 |
| – at a temperature of –20 °C [mm$^2$/s] | – | 3.70 |
| Oxidation stability [h] | 8 | – |
| Cloud point [°C] | –4.6 | 〈 –54 |
| Acid number [mg KOH/g] | 0.21 | 0.006 |
| Flash point [°C] | 176 | 48 |
| Aromatic hydrocarbons content [%, by mass] | 0 | 16.2 |

## 3. Method of testing

The tests were carried out on the following fuel samples:

A – pure RME;

mixtures with the following volumetric compositions:

B – 10 % Jet A 1 and 90 % RME;

C – 20 % Jet A 1 and 80 % RME;

D – 30 % Jet A 1 and 70 % RME;

E – 40 % Jet A 1 and 60 % RME;

F – 50 % Jet A 1 and 50 % RME; and

G – pure Jet A 1.

Prior to the tests, the two basic fuels were filtered with using a 0.8 μm membrane filter for particulate contaminants to be removed; then, the mixtures of both fuels were prepared. Afterwards, both the pure fuels as well as their blends were subjected to measurements of their characteristics under examination. The fuels and their blends were poured into glass vessels of 2 dm$^3$ and 1 dm$^3$ capacity. The ageing was forced by the presence of atmospheric oxygen, impact of sunlight and heat, and presence of water. In total, 42 samples were prepared for the tests.

The samples were divided into two groups:

- 28 samples kept in glass vessels of 2 dm3 capacity each, with 14 of them having a 2 % water admixture, by volume, and the other 14 samples having no water content. In each of the subgroups, 7 vessels were filled with the samples to 75 % of their capacity and the other 7 vessels were filled to 37.5 % of their capacity. All the test vessels were hermetically sealed to prevent any exchange of fuel vapours with atmospheric air. All the samples were stored for 15 weeks in a room where the ambient temperature was within limits of 20-25 °C, with sunlight access.

- 14 samples kept in glass vessels of 1 $dm^3$ capacity each, with all the vessels being filled to 75 % of their capacity. A half (7) of the samples had a 2 % water admixture, by volume. All the samples, hermetically sealed, were stored for 15 weeks in a heat chamber at a temperature of 50-55 °C, with no sunlight access.

In general, 42 fuel samples were subjected to the ageing tests. Following the 15-week ageing process, every sample was vigorously shook and filtered and then placed in hermetically sealed conical flasks, from which fuels were taken for tests. The following fuel characteristics were determined after the ageing process:

- density at a temperature of 15 °C ($\rho_{15}$);
- kinematic viscosity at a temperature of 40 °C ($\nu_{40}$);
- oxidation stability ($OU$);
- acid number ($L_K$).

The density was determined with using a densitometer, in compliance with the requirements of Polish Standard PN-EN ISO 3675:2004. The viscosity was measured in compliance with the requirements of Polish Standard PN-EN ISO 3104:2004 and the oxidation stability was measured in compliance with Polish Standard PN-EN 16091:2011, with using a PetroOXY instrument. The acid number was determined by the potentiometric titration method, based on Polish Standard PN-C-04049:1988, with using the 702 SM Titrino apparatus.

## 4. Test results and a discussion

Results of determining the density, viscosity, acid number, and oxidation stability of fresh fuels (RME, Jet A 1, and their blends) have been given in Table 2.

Table 2. Results of determining the density, viscosity, acid number, and oxidation stability of fuel samples in their original state

| Description | Sample | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| Density at 15 °C [kg/$m^3$] | 883,5 | 875,0 | 867,0 | 859,0 | 850,5 | 840,5 | 796,0 |
| Kinematic viscosity at 40 °C [$mm^2/s$] | 4,44 | 3,79 | 3,31 | 2,96 | 2,62 | 2,26 | 1,18 |
| Acid number [mg KOH/g] | 0,21 | 0,18 | 0,17 | 0,14 | 0,13 | 0,11 | 0,01 |
| Oxidation stability [min] | 52,60 | 58,09 | 62,87 | 69,42 | 77,33 | 87,80 | 424,38 |

As expected, the adding of the Jet A 1 fuel to RME changed the characteristics of the latter to a degree depending on the Jet A 1 content in the blend. With increasing Jet A 1 content, the blend density declined linearly and this may be described by a regression equation:

$$\rho = -0.8471 \times V + 883.76 \quad (1)$$

where: $V$ – Jet A-1 content in the blend, by volume,

with the coefficient of determination being $R^2$ = 0.9986. These results are consistent with those presented in [3].

As it was in the case of density, the viscosity of the RME and Jet A 1 blend declined with increasing Jet A 1 content in the blend. This relation may be described by an exponential regression equation:

$$\nu = -4.3735 \times e^{0.013 \times V} \tag{2}$$

with the coefficient of determination being $R^2 = 0.9973$. The nature of this relation is consistent with that presented in [3].

The RME and Jet A 1 fuels significantly differed from each other in the value of the acid number: the acid number of the biofuel was about 21 times as high as that of Jet A 1. The acid number of a blend of these two fuels changed linearly depending on their contents in the blend. This relation may be described by a regression equation as follows:

$$L_K = -0.0019 \times V + 0.2052 \tag{3}$$

with the coefficient of determination being $R^2 = 0.981$.

The oxidation stability (OU) test carried out by the PetroOXY method revealed a very big difference between the stability of pure RME (52.60 min) and pure Jet A 1 aviation fuel (424.38 min): the oxidation stability of the Jet A 1 fuel was found to be about 8 times as high as that of RME (Fig. 1).

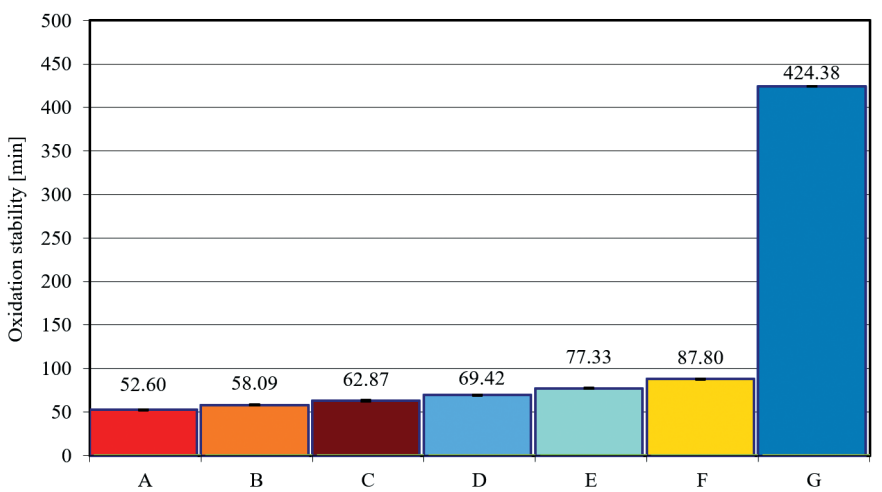


Fig. 1. Oxidation stability of the fuel samples under test

For blends, a growth in the biofuel's oxidation stability can be observed with increasing volumetric content of the Jet A 1 fuel in the blend. However, this growth in the oxidation stability is not very big, if the oxidation stability of the Jet A 1 fuel being eight times as high as that of RME is compared with the oxidation stability of the 50/50 % (v/v) blend of Jet A 1 and

RME, which is merely about 1.7 times as high as that of pure RME. This is because of the specificity of the method of determining this parameter: during the test, the temperature is about 140 °C, the fuels are exposed to the action of pure oxygen, and a 10 % reduction in the oxygen pressure in the reaction vessel with a sample of the fuel under test is taken as a criterion of the measurement (Fig. 2).

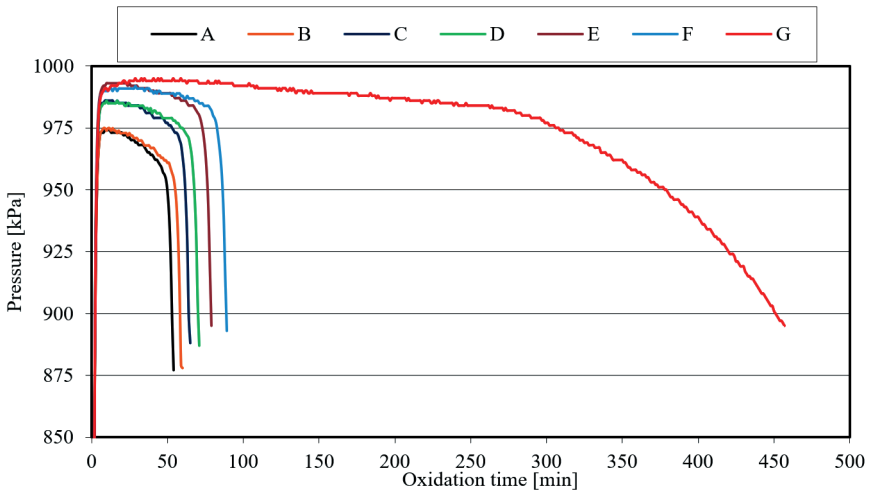


Fig. 2. Oxygen pressure in the reaction vessel with a sample of the fuel under test vs oxidation time

In consequence, the presence of even a big quantity of the Jet A 1 fuel in the mixture does not considerably raise the oxidation stability of the blend. The RME component, which is far more susceptible to oxidation, is oxidized at first and very quickly, while the oxidation of the Jet A 1 component has not started yet. The oxidation stability of the RME and Jet A 1 blend may be described by a regression equation in the form of a second-degree polynomial:

$$OU = 0.0067 \times V^2 + 0.3524 \times V + 53.0849 \tag{4}$$

with the coefficient of determination being $R^2 = 0.9983$ (Fig. 3).

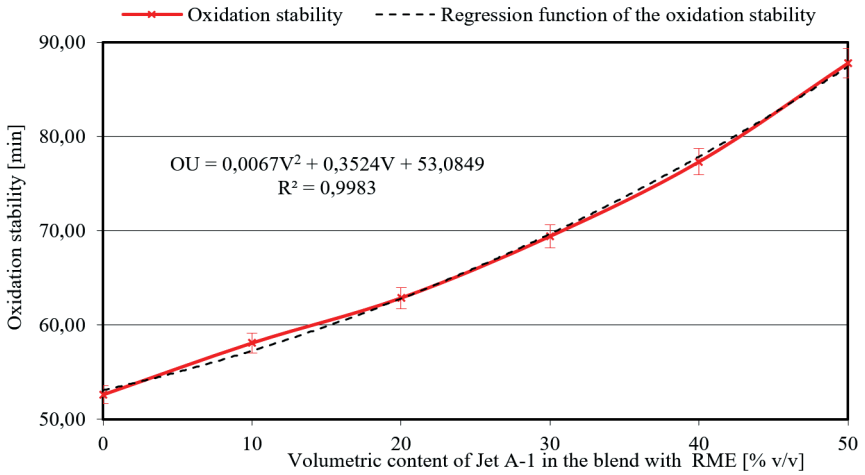


Fig. 3. Oxidation stability of the RME and Jet A 1 blends (with up to 50 % Jet A 1 content, by volume)

The results of measurements of the same characteristics of the samples of both fuels and their blends subjected to the process of ageing in different conditions for 15 weeks were very diverse. No changes in the density and viscosity of pure Jet A 1 fuel occurred in any variant of the ageing process. For the other samples, their density slightly increased (by up to about 0.4 %). The biggest gain in the density values was recorded for the samples that were kept at a temperature of 20-25 °C in vessels filled to 37.5 % of their capacity (i.e. with more air being present in the vessel), were exposed to sunlight, and contained a 2 % water admixture. Conversely, the smallest density gains occurred for the samples that were stored at a temperature of 20-25 °C in vessels filled to 75 % of their capacity, with no presence of water. This shows that fuel density measurements cannot be considered a sufficiently sensitive indicator to describe the process of ageing of RME and its mixtures with the Jet A 1 fuel.

The ageing processes resulted in a small growth in the values of viscosity of the fuel samples under test (Table 3).

Table 3. Values of the kinematic viscosity of fuel samples at 40 °C, depending on the conditions of the 15 week ageing process [mm²/s]

| Item | Ageing conditions | Sample | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| 1. | Samples in their original state | 4.44 | 3.79 | 3.31 | 2.96 | 2.62 | 2.26 | 1.18 |
| 2. | Solar light, temperature 20-25 °C, vessel filled to 37.5 % of its capacity | 4.50 | 3.86 | 3.35 | 3.02 | 2.68 | 2.29 | 1.18 |
| 3. | Solar light, temperature 20-25 °C, vessel filled to 37.5 % of its capacity, 2 % water admixture | 4.49 | 3.98 | 3.41 | 3.07 | 2.69 | 2.30 | 1.18 |
| 4. | Solar light, temperature 20-25 °C, vessel filled to 75 % of its capacity | 4.45 | 3.91 | 3.34 | 2.98 | 2.62 | 2.26 | 1.18 |
| 5. | Solar light, temperature 20-25 °C, vessel filled to 75 % of its capacity, 2 % water admixture | 4.48 | 3.83 | 3.33 | 2.96 | 2.22 | 2.26 | 1.18 |
| 6. | Temperature 50-55 °C, vessel filled to 75 % of its capacity | 4.46 | 3.88 | 3.31 | 3.02 | 2.66 | 2.28 | 1.18 |
| 7. | Temperature 50-55 °C, vessel filled to 75 % of its capacity, 2 % water admixture | 4.71 | 3.80 | 3.31 | 2.96 | 2.62 | 2.27 | 1.18 |

As it was in the case of density, no change in the viscosity of pure Jet A 1 fuel was recorded in any variant of the ageing process. For the other samples (pure RME and mixtures), the viscosity values were observed to increase by 0.23 % to 3 %; there were also two cases where the viscosity grew by about 5 % and 6 %. The biggest gains in the viscosity values occurred for the samples of:

- pure RME exposed to raised temperature and containing a 2 % v/v water admixture (gain by 0.27 mm2/s, i.e. by 5.75 %);
- mixture with 10 % of Jet A 1 and 90 % of RME, by volume, aged at a temperature of 20-25 °C in a vessel filled to 37.5 % of its capacity, and containing a 2 % v/v water admixture (gain by 0.19 mm2/s, i.e. by 5.01 %);
- mixture with 30 % of Jet A 1 and 70 % of RME, by volume, aged in identical conditions (gain by 0.11 mm2/s, i.e. by 3.72 %).

The biggest gain in the viscosity values (by 2.72 %, on average, in relation to those of the samples in their original state) occurred in the samples that were exposed to sunlight, with greater oxygen access (the vessel was filled to 37.5 % of its capacity), and that contained a 2 % water admixture. The smallest viscosity changes were observed in the samples that were subjected to ageing at less access of air (the vessel was filled to 75 % of its capacity): in such a case, the viscosity value grew by as little as 0.49 %.

This shows that the factors that have the greatest impact on the growth in the viscosity of fuels in the ageing process are the access of oxygen and the action of heat: in the samples subjected to ageing at a temperature of 50-55 °C, the gain in the viscosity values was about 3 times as big as that observed in the samples where the ageing temperature was 20-25 °C (at identical filing of the vessel).

After completion of the 15-week ageing period, a growth in the acid number was recorded in all the samples under test (Table 4).

Table 4. Acid number of the fuel samples, depending on the conditions of the 15 week ageing process [mg KOH/g]

| Item | Ageing conditions | Sample | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| 1. | Samples in their original state | 0.21 | 0.18 | 0.17 | 0.14 | 0.13 | 0.11 | 0.01 |
| 2. | Solar light, temperature 20-25 °C, vessel filled to 37.5 % of its capacity | 0.24 | 0.23 | 0.21 | 0.20 | 0.17 | 0.16 | 0.07 |
| 3. | Solar light, temperature 20-25 °C, vessel filled to 37.5 % of its capacity, 2 % water admixture | 0.26 | 0.25 | 0.25 | 0.24 | 0.23 | 0.19 | 0.07 |
| 4. | Solar light, temperature 20-25 °C, vessel filled to 75 % of its capacity | 0.24 | 0.20 | 0.19 | 0.17 | 0.16 | 0.15 | 0.07 |
| 5. | Solar light, temperature 20-25 °C, vessel filled to 75 % of its capacity, 2 % water admixture | 0.25 | 0.23 | 0.21 | 0.20 | 0.18 | 0.17 | 0.04 |
| 6. | Temperature 50-55 °C, vessel filled to 75 % of its capacity | 0.23 | 0.21 | 0.20 | 0.18 | 0.17 | 0.15 | 0.03 |
| 7. | Temperature 50-55 °C, vessel filled to 75 % of its capacity, 2 % water admixture | 1.00 | 0.27 | 0.26 | 0.23 | 0.21 | 0.17 | 0.05 |

Among all the fuel samples under test, both in their original state and after ageing, the highest values of the acid number were recorded for pure RME; conversely, the lowest values were recorded for pure Jet A 1 fuel. The adding of the Jet A 1 fuel to the mixture caused a reduction in the acid number for all the variants of the ageing process. The degree of this reduction increased with rising Jet A 1 fuel content in the Jet A 1 and RME mixture.

The results obtained show that the acid number values were higher for the samples with a greater access of air to the fuel. The growth in the acid number values during the ageing process was also bigger for the samples with water content. The highest values of this growth were recorded for pure RME subjected to ageing at the raised temperature. The data presented in Table 4 show that the adding of the Jet A 1 fuel to the blend caused

a reduction in the acid number of the Jet A 1 and RME mixture, i.e. the Jet A 1 admixture inhibited the intensity of the blend ageing process.

A comparison of the data presented in Tables 3 and 4 shows that the growths in the viscosity and acid number of the fuel blends took place at the same conditions of the ageing process.

It should be noted that the conditions of the ageing process were characterized by strong incentive impacts, in result of which even the Jet A 1 fuel underwent oxidation. Although the acid number values were very low as such (within the range of 0.03-0.07 mg KOH/g), they were 3 to 7 times as high as those determined for the fuel samples in their original state.

After completion of the 15-week ageing period, a decline in the oxidation stability values was recorded for all the fuel samples under test.

## 5. Conclusions

1. The investigation results obtained should be treated as preliminary findings.
2. An admixture of the Jet A 1 aviation fuel causes reductions in the density, kinematic viscosity, and acid number and a growth in the oxidation stability of the RME fuel.
3. An admixture of the Jet A 1 aviation fuel causes a reduction in the intensity of ageing, including reductions in the rates of growth in the viscosity and acid number, of the RME fuel.
4. The decisive impact on changes in the quality characteristics of the RME and Jet A 1 blends during the ageing process is exerted by the action of air and heat and by the presence of water.
5. The adding of the Jet A 1 aviation fuel may be one of the possible methods of improving the ageing stability of the RME-based fuels.

The full text of the article is available in Polish online on the website http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie http://archiwummotoryzacji.pl.

## References

[1] Baczewski K, Seroka M, Szczawiński P. Badania właściwości reologicznych mieszanin RME z paliwem lotniczym Jet A-1 (Investigations of rheological properties of rapeseed oil methyl esters and aviation turbine fuel Jet A-1 blends). Aparatura Badawcza i Dydaktyczna. 2013; 4: 23-28. ISSN 1426-9600.

[2] Baczewski K, Szczawiński P. Investigation of impacting of aging processes on properties of biodiesel. Journal of KONES. 2007; 14(2): 27-34. ISSN 1231-4005.

[3] Baczewski K, Szczawiński P. Investigation properties of rapeseed oil methyl esters/aviation turbine fuel Jet A-1 blends. Journal of KONES. 2011; 18(1): 15-22. ISSN 1231-4005.

[4] Berrios M, Martín M A, Chica A F, Martín A. Storage effect in the quality of different methyl esters and blends with diesel. Fuel. 2012; 91: 119-125. ISSN 0016-2361.

[5] Christensen E, McCormick R L. Long-term storage stability of biodiesel and biodiesel blends. Fuel Processing Technology. 2014; 128: 339-348. ISSN 0378-3820.

[6] Kumar N. Oxidative stability of biodiesel: Causes, effects and prevention. Fuel. 2017; 190: 328-350. ISSN 0016-2361.

[7] Uyumaz A, Solmaz H, Yilmaz E, Yamik H, Polat S. Experimental examination of the effects of military aviation fuel JP-8 and biodiesel fuel blends on the engine performance, exhaust emissions and combustion in a direct injection engine. Fuel Processing Technology. 2014; 128: 158-165. ISSN 0378-3820.