

INVESTIGATION PROPERTIES OF RAPESEED OIL METHYL ESTERS/AVIATION TURBINE FUEL JET A-1 BLENDS

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Abstract

The properties of rapeseed methyl ester (RME) and commercial biodiesel (B100) blends with aviation turbine fuel Jet A-1 were investigated. The RME (without improving additives) and B100 (with improving additives – including antioxidants and depressants) were blend with Jet A-1 fuel, to made six mixtures containing: 10%, 20%, 30%, 40%, 50% and 60% Jet A-1 by volume. Their blends were stable. Jet A-1 fuel and RME (B100) blends properties are indirect between Jet A-1 and RME properties. The density, kinematic viscosity at 40 °C, cloud point (CP), cold filter plugging point (CFPP) and pour point (PP) RME, B100, Jet A-1 and their blends were measured. Adding the Jet A-1 fuel to the RME and B100 can be the method to improve its low temperature properties.

The empirical equations for calculation the density, kinematic viscosity at 40 °C, cloud point, cold filter plugging point and pour point RME (B100) blends with Jet A-1 fuel as a function of composition for predicting the properties of RME (B100) blends with aviation turbine fuel Jet A-1 give values in good agreement with experiments.

There is good agreement between experimental viscosity data of blends with viscosity calculated with mixture equation by Arrhenius.

Keywords: biodiesel, rapeseed oil methylester (RME), aviation fuels, kinematic viscosity, low-temperature properties of biofuels

1. Introduction

Renewable fuels manufactured by the estrification of vegetable oils or animal fats can be used as a substitute for or as an additive to mineral diesel fuels. Such fuels are named as biodiesel. Common source of biodiesel in Poland is rapeseed oil.

Biodiesel is obtained by converting pure fatty acid into mono-alkyl esters by transestrification – Fatty Acid Methyl Ester (FAME) or Fatty Acid Ethyl Ester (FAEE). Esters obtained from rapeseed oil and methyl alcohol have acronym as RME (Rapeseed Methyl Ester). RME (Biodiesel) and its blends with petroleum based diesel fuel can be used in diesel engines without any significant modifications to the engines [1].

The advantages of biodiesel (RME) over petroleum diesel fuel are improved lubricity, a higher flash point, lower toxicity and biodegradability [1]. Since biodiesel is oxygenated, combustion is more complete and produces fewer harmful emission and pollutants (particulate matter, hydrocarbons, carbon monoxide).

The disadvantages of biodiesel are its poor low temperature flow properties since it begins to gel at low temperature [1, 2, 3]. It can clog filters or even become so thick that it can not be pumped from the fuel tank to the engine. The low temperature properties of biodiesel can be improve by winterisation [4], by adding of the depressants [1, 3] or using biodiesel – diesel fuel blends [5, 6, 7, 8].

The cloud point (CP), cold filter plugging point (CFPP) and pour point (PP) of RME are higher than conventional diesel fuel [1, 8]. Both CP, CFPP and PP of RME (biodiesel) and its blends with

diesel fuel decreases with biodiesel concentration [1, 7, 8] and by additional of different depressants [8].

Aviation turbine fuel Jet A-1 contains molecules of hydrocarbons, with typical molecule containing between 9 and 16 carbon atoms and approximately twice as many hydrogen atoms. A typical RME molecule contains between 16 and 18 carbon atoms, approximately twice as many hydrogen atoms, and two oxygen atoms. Note that the molecules in RME are very similar to the molecules in Jet A-1 fuel, and, from the point of view of chemistry and physics, the two fuels are similar in all respects.

The two fuels can be blend together. Adding the Jet A-1 fuel to the RME can be the method to improve its low temperature properties.

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The present work deals with the measurement of density, kinematic viscosity, cloud point, cold filter plugging point and pour point of biodiesel (RME and B100) and their blends with aviation turbine fuel Jet A-1. Jet A-1 fuel has very good low temperature properties and other properties near of diesel fuels properties. Jet A-1 fuel and RME (B100) blends properties are indirect between of Jet A-1 and RME properties. Their blends are stability.

The empirical equations for predicting the density, kinematic viscosity at 40°C, cloud point, cold filter plugging point and pour point as function of aviation turbine fuel Jet A-1 and RME (B100) blends composition are given.

2. Experimental procedures

2.1. Fuel and blends

Two samples of RME were used. One sample was based on pure RME (without improving additives) and second sample was based on commercial RME (B100) with improving additives (including antioxidants and depressants).

Each sample of the RME was blended with aviation turbine fuel Jet A-1 to made six mixtures containing 10%, 20%, 30%, 40%, 50% and 60% Jet A-1 by volume. The samples were indicated as:

1. RME/10, RME/20, RME/30, RME/40, RME/50 and RME/60,
2. B100/10, B100/20, B100/30, B100/40, B100/50 and B100/60.

Initially parameters of testing fuels are listed in Table 1.

Tab. 1. Main parameters of tested fuels

Parameter	RME	B100	Jet A-1
Fuel standard	EN 14214+A1:2010	EN 14214+A1:2010	ASTM D 1655-10
Density at 15°C. kg/m ³	882	882	802
Kinematic viscosity at 40°C. mm ² /s	4.37	4.43	1.24
Cloud Point. °C	-4.1	-5.0	-26.0
Cold Filter Plugging Point. °C	-15	-26	-46
Pour Point. °C	-12	-42	-51

All fuels blends were filtered by microfilter 0.8 µm. Blending was carried out at room temperature by adding a measured volume of the Jet A-1 fuel to the RME or B100 under continuous agitation.

The density, viscosity and low temperature properties (Cloud Point, Cold Filter Plugging Point, Pour Point) of the RME, B100, Jet A-1 and their blends were determined.

2.2. Fuel properties measurements

Density was measured according to EN ISO 3675 at the temperature of 15°C by hydrometer method.

Kinematic viscosity was measured according to EN ISO 3104 which defines this property as the resistance to flow of a fluid under gravity at 40°C. The testing devices were calibrated viscometers of the capillary Ostwald-Pinkevitch.

Kinematic viscosity was measured within the limits of precision given in the time for a fixed volume of liquid to flow under gravity through a capillary at a known and closely controlled temperature (40±0,1°C). The kinematic viscosity is calculated as follows:

$$\eta = k \cdot \tau, \quad (1)$$

where:

η – kinematic viscosity, mm²/s,

k – calibration constant of the viscometer, mm²/s²,

τ – mean flow time, s.

Cloud point and pour point – cloud point (CP) was measured according to ISO 3015. Following this standard, to determine cloud point a 45 cm³ sample was cooled at specified rate and examined periodically. The testing device was a automatic cloud/pour point measuring CPP 97-2 (ISL, France) apparatus.

Pour point (PP) was measured according to ISO 3016. To determine pour point a 45 cm³ sample initially at 45°C is cooled at specified rate and examined in intervals of 3°C for flow characteristics (the apparatus checks if the sample is still moving). PP is the temperature of solid sample minus 3°C. The testing device was a automatic cloud/pour point measuring CPP 97-2 (ISL, France) apparatus.

Cold filter plugging point (CFPP) was measured according to EN 116. This test provides an estimate of the lowest temperature at which a fuel will give trouble free flow in certain fuel systems. The testing device, to obtain CFPP, according to this standard, was also automatic CPP 97-2 apparatus.

3. Results and discussion

The results of density tests on fuels and their mixtures are shown in Fig. 1.

The density of the RME or B100 mixture with Jet A-1 fuel decreases by increasing Jet A-1 fuel content in the blend. It is a linear dependence and can be described by the following formula:

$$\rho_{15} = -80 \cdot v + 882, \quad (2)$$

where:

ρ_{15} – density of the RME or B100 blend with Jet A-1 fuel at 15°C, kg/m³,

v – Jet A-1 volume fraction in the blend with RME or B100.

The density is additive property of blend. This means that when RME (B100) and Jet A-1 fuel are blended, there is no change in the volume occupied by molecule and no change in energy. There reasonable assumptions considering the large number of atoms in each molecule, the similar of the molecules, and lack of any chemical reaction between them.

The regression coefficient (R^2) was greater than 0.99 (Fig. 1), indicating, that linear regression accurately represents the density – volume fraction of Jet A-1 fuel in blends relationship for the fuels tested.

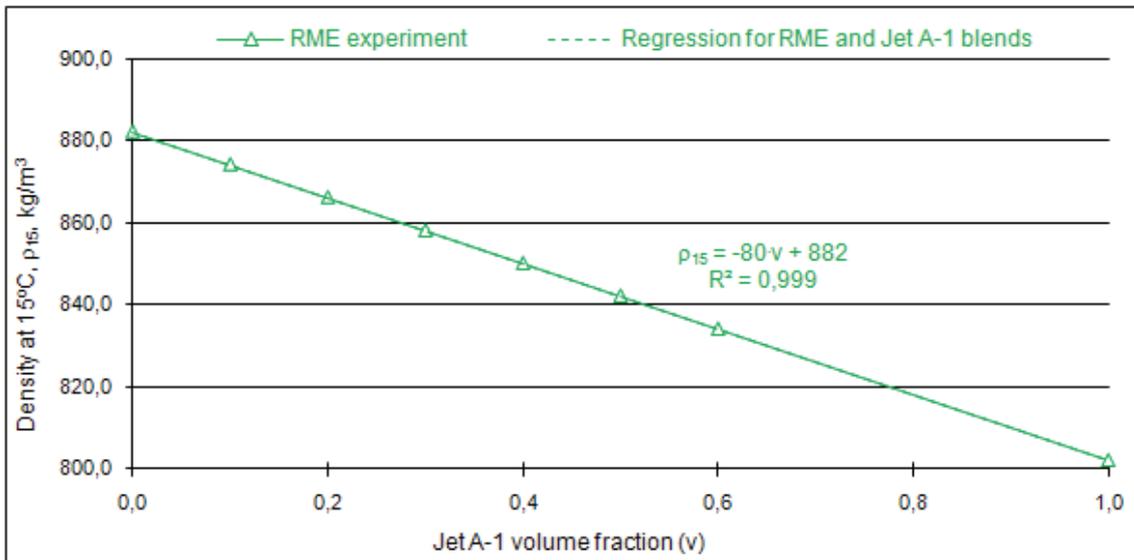


Fig. 1. Density versus aviation fuel Jet A-1 volume fraction for the RME–Jet A-1 blends

The effect of Jet A-1 fuel content on the viscosity (at 40°C) of blends is shown in Fig. 2.

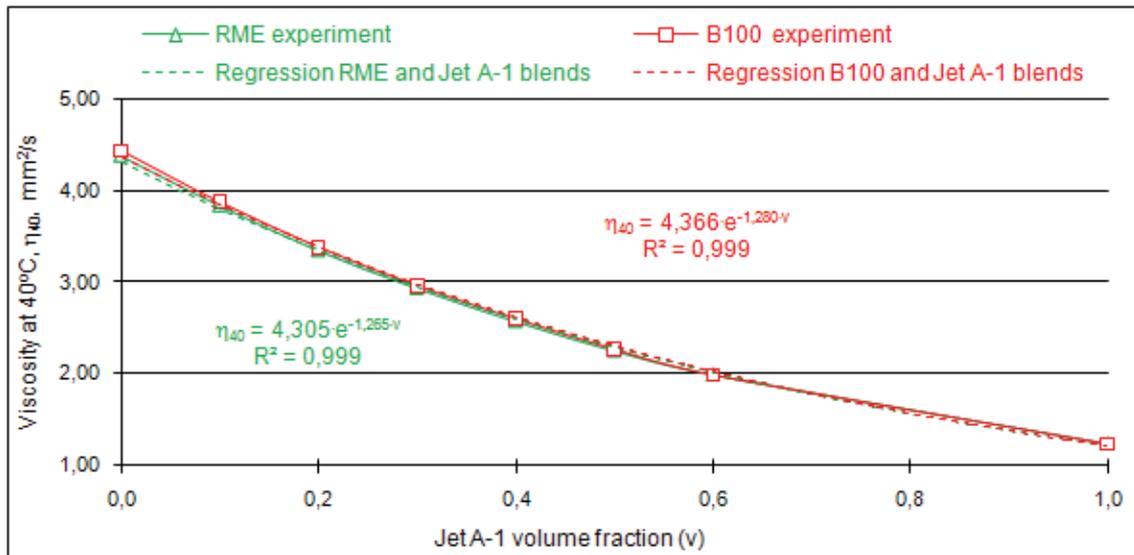


Fig. 2. Viscosity versus aviation fuel Jet A-1 volume fraction for the B100–Jet A-1 and RME–Jet A-1 blends

Kinematic viscosities of the RME or B100 blends with Jet A-1 fuel show decreasing tendency with increasing amount of Jet A-1 fuel in the blend (Fig. 2). It was found that the content of Jet A-1 fuel dependence of the viscosity of blends with RME (B100) could be satisfactorily described by the experimental relationship:

$$\eta_{40} = A \cdot e^{B \cdot v}, \quad (3)$$

where:

η_{40} – kinematic viscosity of the RME or B100 blend with Jet A-1 fuel at 40°C, mm²/s,

A – const. 4.366 for B100 and 4.305 for RME,

B – const. 1.280 for B100 and 1.265 for RME.

The great (0.999) regression coefficient (R^2) indicates, that regression equation (3) accurately represents the viscosity η_{40} – volume content of Jet A-1 fuel in tested blends (Fig. 2).

The viscosity of mixture can be predicted theoretically. The Grunberg–Nissan mixing rule is widely used for predicting viscosity of liquid mixtures [9]:

$$\ln \eta_{blend} = \sum_i^n x_i \ln \eta_i + \sum_i^n \sum_j^n x_i x_j G_{ij}, \quad (4)$$

where:

η_{blend} – mean absolute viscosity of the blend,

η_i – the absolute viscosity of pure i^{th} component,

x_i, x_j – the mole fractions of the i^{th} and j^{th} components,

G_{ij} – the interaction parameter ($G_{ij} = 0$, for $i = j$),

n – the number of components.

When the components of a mixture have similar chemical structure it is expected that they do not interact with each other and consequently the interaction parameter in Eq. (4) can be neglected. The RME (B100)–Jet A-1 fuel blends can be assumed to behave this way because both liquids are non-polar, completely miscible, and when blended their volumes are practically additive.

The Eq. (4) for binary mixture takes the form of Arrhenius equation:

$$\ln \eta_{blend} = v_1 \cdot \ln \eta_1 + l \eta_2, \quad (5)$$

where:

η_{blend} – the viscosity of the blend at a particular temperature (40°C), mm^2/s ,

v_1, v_2 – the volume fractions of the two components,

η_1, η_2 – the viscosity of the two components at same temperature (40°C) as the blend, mm^2/s .

By means of Eq. (5), it is possible to predict the viscosity of RME (B100)–Jet A-1 fuel blends at temperature 40°C. There is good agreement between viscosities predicted using the Eq. (3), Eq. (5) and experimental viscosity data for the RME (B100)–Jet A-1 fuel blends over the whole range of contents studied (Table 2, Fig. 2, Fig. 3 and Fig. 4).

Tab. 2. Measured and calculated kinematic viscosity of RME (B100) and Jet A-1 fuel blends

Content of Jet A-1 in blend with RME	0.0	0.1	0.2	0.3	0.4	0.5	0.6	1.0
η_{40} measured, mm^2/s	4.37	3.83	3,34	2.93	2.57	2.25	1.99	1,24
η_{40} calculated with equation (3), mm^2/s	–	3.79	3.34	2.95	2.60	2.29	2.02	–
η_{40} calculated with equation (5), mm^2/s	–	3.85	3.40	2.99	2.64	2.33	2.05	–
Content of Jet A-1 in blend with B100	0.0	0.1	0.2	0.3	0.4	0.5	0.6	1.0
η_{40} measured, mm^2/s	4.43	3.87	3.38	2.96	2.60	2.27	1.99	1.24
η_{40} calculated with equation (3), mm^2/s	–	3.84	3.38	2.97	2.62	2.30	2.03	–
η_{40} calculated with equation (5), mm^2/s	–	3.90	3.43	3.02	2.66	2.34	2.06	–

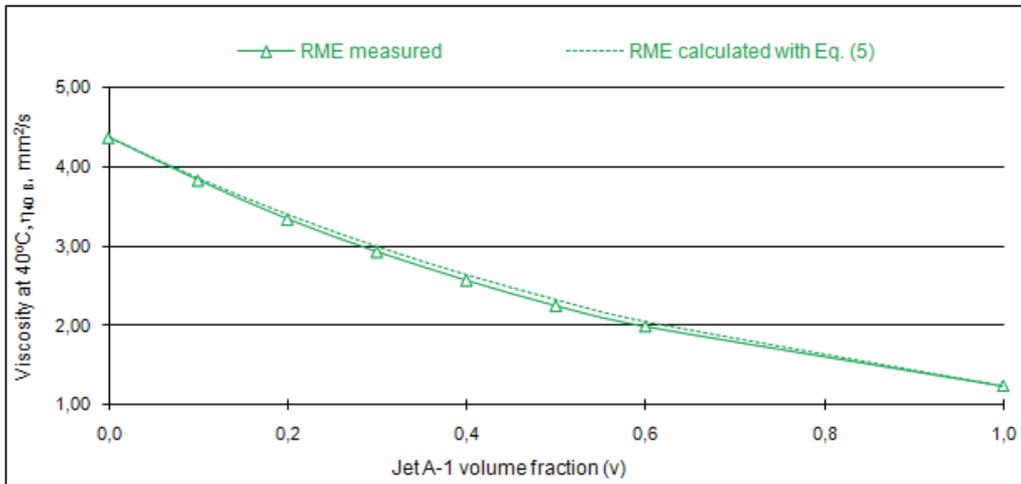


Fig. 3. Measured and calculated kinematic viscosity (at 40°C) of RME and Jet A-1 fuel blends

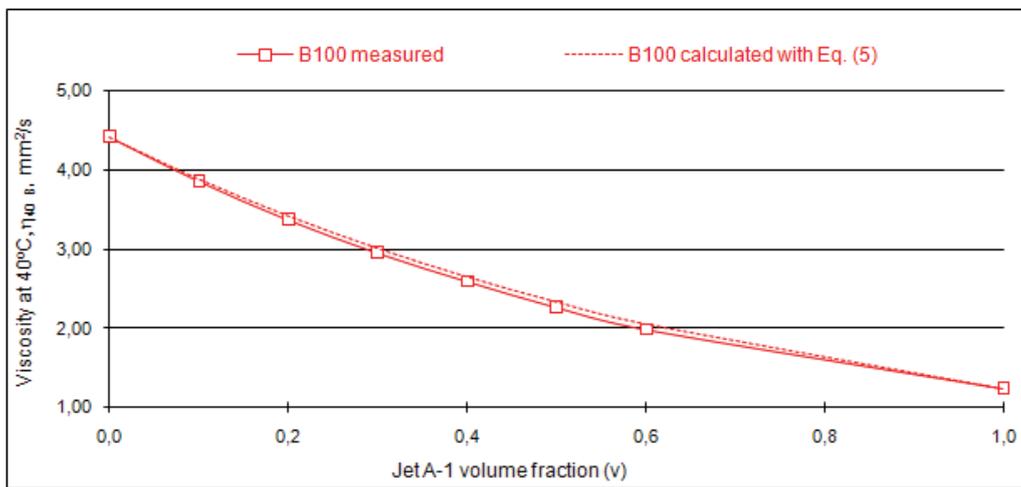


Fig. 4. Measured and calculated kinematic viscosity (at 40°C) of B100 and Jet A-1 fuel blends

By comparing predicted values of kinematic viscosity from Eq. (3) with experimental data it is found that the typical average errors were less than 1%. The kinematic viscosity of RME (B100)–Jet A-1 fuel blends estimated by Eq. (5) were generally about 1...3% higher than the measured values (Table 2).

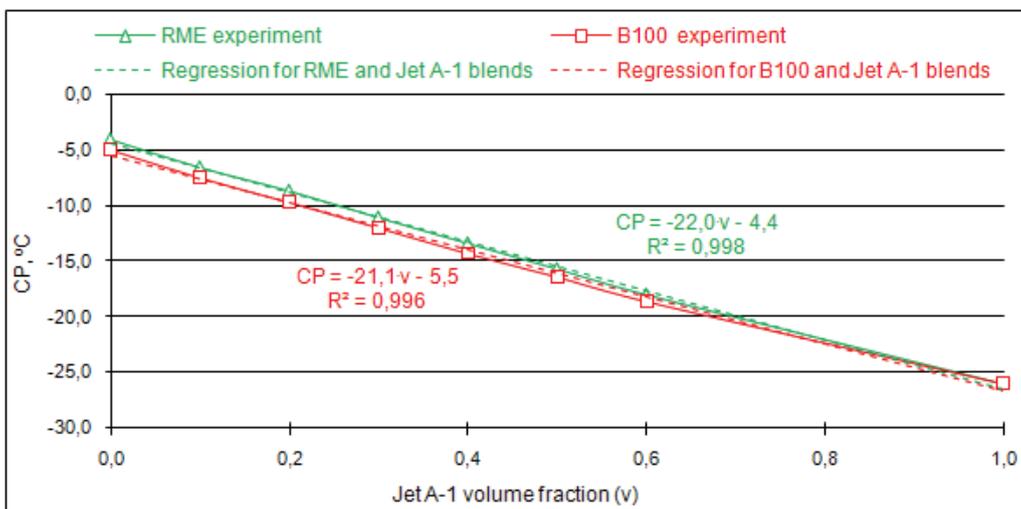


Fig. 5. Cloud point of blends of Jet A-1 in B100 and RME

The results of low temperature properties tests on fuels and their mixtures are shown in: Fig. 5 (cloud point), Fig. 6 (pour point) and Fig. 7 (cold filter plugging point).

In general, the cloud point (CP), pour point (PP) and cold filter plugging point (CFPP) decreased with Jet A-1 fuel concentration. The relation in CP of RME was from -4°C to -8°C when blended with 20% of Jet A-1 fuel, and of B100 was from -5°C to -10°C , respectively. Similarly the reduction in PP of RME was from -11°C to -18°C when blended with 20% of Jet A-1 fuel and up to -28°C when blended with 40% Jet A-1 fuel.

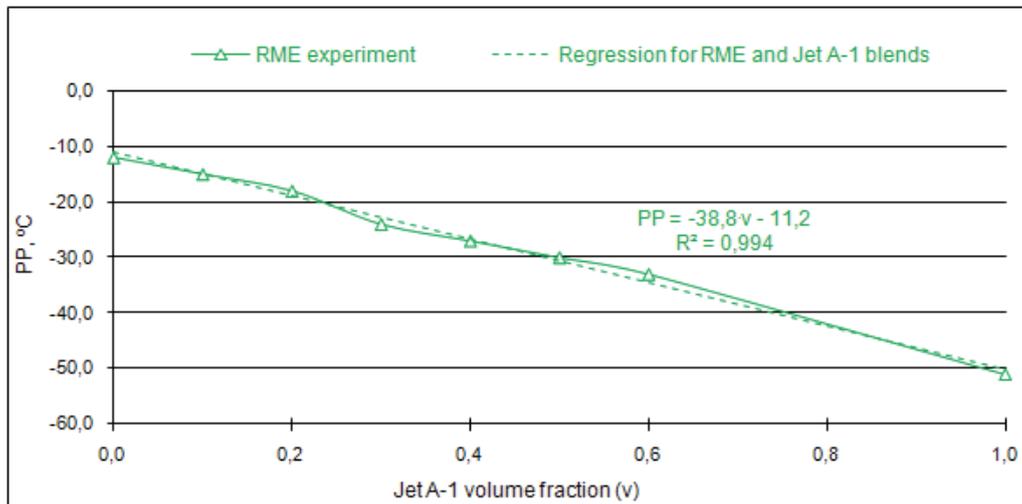


Fig. 6. Pour point of blends of Jet A-1 in RME

The CFPP decreased less intensity than CP and PP in function of Jet A-1 fuel concentration in blends with RME and B100. The relation in CFPP of RME was from -15°C to -20°C when blended with 20% of Jet A-1 fuel, and from -26°C to -30°C for B100, respectively.

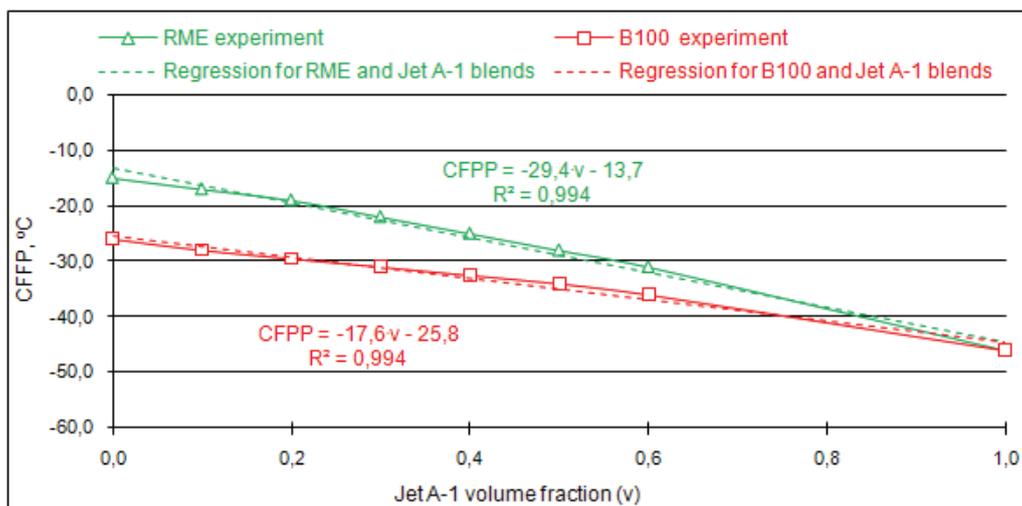


Fig. 7. Cold filter plugging point of blends of Jet A-1 in B100 and RME

The results show that blending RME or B100 with Jet A-1 fuel their cold temperature properties can be improved to levels that are comparable to petrodiesel. The blends RME with 40% of Jet A-1 fuel have the cold temperature properties to conform class N⁰ of arctic diesel fuels.

The measurements have been correlated as a function of blend by empirical linear equations. In this study the following correlations were obtained:

$$\text{for CP: } T_{CP-RME} = -22.0 \cdot v - 4.4 \quad R^2 = 0.998, \quad (6)$$

$$T_{CP-B100} = -211 \cdot v - 5.5 \quad R^2 = 0.996, \quad (7)$$

$$\text{for PP: } T_{PP-RME} = -388 \cdot v - 11.2 \quad R^2 = 0.994, \quad (8)$$

$$\text{for CFPP: } T_{CFPP-RME} = -29.4 \cdot v - 13.7 \quad R^2 = 0.994, \quad (9)$$

$$T_{CFPP-B100} = -17.6 \cdot v - 25.8 \quad R^2 = 0.994, \quad (10)$$

where:

T – temperature, °C,

v – the volume fraction of Jet A-1 fuel in the blend with RME or B100.

The correlation coefficient, R^2 , of those equations was all better than 0.99 suggesting that CP, PP and CFPP can be calculated as a function of the Jet A-1 fuel fraction. The results obtained are in agreement with previous work [8].

4. Conclusions

1. The properties of RME (B100)–Jet A-1 fuel blends were investigated. The data obtained were used to describe and develop rheological and low temperature properties of those blends.
2. Experimental data showing the variation of density and kinematic viscosity of RME (B100)–Jet A-1 fuel blends were properly fitted by means of statistical regressions.
3. An empirical equation describing the kinematic viscosity of RME (B100) with Jet A-1 fuel blends as a function of volume fraction of Jet A-1 fuel has been developed. The regression model and the Arrhenius viscosity mixing equation can be used to predict blend kinematic viscosity at any composition of RME (B100) and Jet A-1.
4. The cloud point, cold filter plugging point and pour point of RME (B100) and Jet A-1 fuel blends have been made. In all cases the CP, CFPP and PP of blends decreased with increase in concentration of Jet A-1 fuel.
5. Empirical equations to predict cloud point, cold filter plugging point and pour point of blends RME (B100) with Jet A-1 fuel have been developed.

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