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TEMPERATURE DEPENDENCE VISCOSITY AND DENSITY OF DIFFERENT BIODIESEL BLENDS

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Abstract

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The main goal of this paper is to assess the effect of rapeseed oil methyl ester (RME) concentration in diesel fuel on its viscosity and density behaviour. The density and dynamic viscosity were observed at various mixing ratios of RME and diesel fuel. All measurements were performed at constant temperature of 40 °C. Increasing ratio of RME in diesel fuel was reflected in increased density value and dynamic viscosity of the blend. In case of pure RME, pure diesel fuel, and a blend of both (B30), temperature dependence of dynamic viscosity and density was examined. Temperature range in the experiment was –10 °C to 80 °C. Considerable temperature dependence of dynamic viscosity and density was found and demonstrated for all three samples. This finding is in accordance with theoretical assumptions and reference data. Mathematical models were developed and tested. Temperature dependence of dynamic viscosity was modeled using a polynomial 3rd polynomial degree. Correlation coefficients R –0.796, –0.948, and –0.974 between measured and calculated values were found. Temperature dependence of density was modeled using a 2nd polynomial degree. Correlation coefficients R –0.994, –0.979, and –0.976 between measured and calculated values were acquired. The proposed models can be used for flow behaviour prediction of RME, diesel fuel, and their blends.

Keywords: biodiesel, density, viscosity, modeling

INTRODUCTION

In the Czech Republic, biofuels are being tested as additives to conventional fuels such as petrol and diesel. The new commitment of the European Union is to increase the share of biofuels in conventional fuels up to 10% by 2020. Now (according with ČSN EN 590) the current state it is about 7%.

The term biofuel means liquid or gaseous fuel that is produced from biomass. Biofuels may include the following products: biodiesel, bioethanol, biogas, biomethanol, bioDME (dimethyl ether), bio-ETBE (ethyl tert-butyl ether), bio-MTBE (methyl tert-butyl ether), synthetic biofuels, hydrogen and pure vegetable oil (Vlk, 2006). Currently biodiesel (made from oil crops, e.g. rapeseed and sunflower) and bioethanol (made from crops containing sugar and starch, e.g. beet or cereals) rank among most widely used biofuels. These two liquid fuels can replace diesel fuel and petrol on a massive scale. They can be used in engines of modern cars. The engines may include unmodified (for low biofuel content) or modified (for high biofuel content). In addition, these fuels shall be distributed through the existing infrastructure (Vlk, 2004).

Production of biodiesel is a well established procedure and the technology will probably stay basically the same. The term biodiesel refers to fatty acid methyl esters (FAME). They are products of a process called esterification, where the reactants are vegetable oil or animal fat and methanol in the presence of a catalyst. A by-product of this process is glycerine which can be used in cosmetics and pharmaceutical industry. Currently 80% of annual world production of biodiesel uses rapeseed oil. The same ratio applies to the Czech Republic, as well. In this case, we refer to the biofuel as rapeseed methyl ester (Králová, 2007).

From theoretical point of view, pure RME can be used in diesel engines directly without any chemical modifications. However, the drawbacks of this approach are its worse properties compared to diesel including viscosity, density, stability, and cetane number. As a result, it is more commonly used in a blend with conventional diesel fuel.

This article addresses issues connected with the viscosity/density of RME, diesel fuel, and blends.

MATERIALS AND METHODS

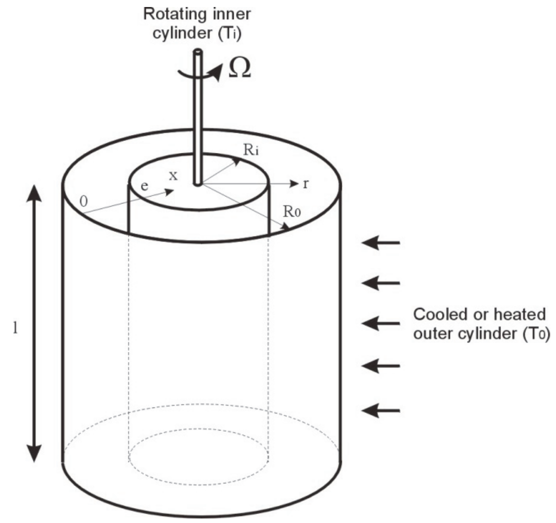
RME, diesel fuel, and 8 of their mutual blends with different mixing ratios have been chosen for the experiment. Samples with volume of 1000 ml were used. Detailed description is given in Tab. I below.

I: *Blends of RME and diesel used in the experiment*

Sample No.	Diesel Fuel		RME	
	ml	%	ml	%
1	1,000	100%	0	0%
2	947	95%	53	5%
3	842	84%	158	16%
4	737	74%	263	26%
5	632	63%	368	37%
6	526	53%	474	47%
7	421	42%	579	58%
8	316	32%	684	68%
9	210	21%	790	79%
10	0	0%	1,000	100%

Viscosity measurements were performed using the Anton Paar DV-3P rotational viscometer. This device measures torque force required to overcome resistance of rotating cylinder or disk immersed in the measured material sample. The rotating cylinder or spindle is connected via spring to motor shaft rotating at defined speed. Rotation of the shaft is measured electronically and provides accurate information about the position of the shaft, hence the spindle (see Fig. 1). The dynamic viscosity value in [mPa·s] is then acquired using internal calculation algorithm. For constant viscosity liquids, the resistance against motion increases with the size of spindle. Measurement range for determination of material rheological properties can be adjusted by selecting the appropriate combination of spindle and rotation speed. To obtain relevant results, it is necessary to know essential rheological properties of given sample. Obviously, it is necessary to correctly classify the material prior any testing takes place (Kumbár and Sabaliauskas, 2013).

Standard spindle labeled LCT was used in the experiment. The spindle is most appropriate for



1: *Schematic of device geometry*

liquids featuring very low viscosity. On the rotational viscometer the number of spindle revolutions was set to 100 per minute and the sampling frequency was set to 1 Hz.

The temperature dependence of viscosity was measured using the following procedure: 200 ml of the measured sample cooled to −10 °C was placed into a beaker. This beaker with the sample was then placed into working vessel of the rotational viscometer. Then, the measuring spindle (LCT) and a calibrated temperature sensor Pt 100 were immersed as well. After that the actual dynamic viscosity measurement began. The sample was further heated up to 80 °C. Presented procedure is in accordance with the references (Kumbár and Polcar, 2012; Kumbár and Dostál, 2014).

Using a simple conversion, we can calculate the kinematic viscosity from the dynamic viscosity measured. The kinematic viscosity is the ratio of dynamic viscosity and density of measured sample:

$$\nu = \frac{\eta}{\rho} \ [\mathrm{mm^2{\cdot}s^{-1}; mPa{\cdot}s, g{\cdot}cm^{-3}}], \quad (1)$$

where
ν .... kinematic viscosity,
η .... dynamic viscosity, and
ρ .... density.

Density measurements were performed using Mohr scales. Sample temperature was 40 °C. This value represents a comparative temperature for distilled liquids according to the ISO 8217 standard.

A mathematical model was created using the Statistica 10 software. Accuracy (suitability) of fitted functions was determined by the correlation coefficient *R*; the degree of significance ($p < 0.05$).

RESULTS AND DISCUSSION

Examination of RME concentration in diesel fuel revealed that with increasing concentration, the density of blend increase dependence is almost linear. This result was expected in accordance with the references (Alptekin and Canakci, 2008; Ramírez-Verduzco *et al.*, 2011). Then, a mathematical model was constructed. In the model, the following linear regression formula was used (Kumbár and Votava, 2014):

$$y = a_1 \cdot x + a_0. \quad (2)$$

After substitution, the formula reads as follows:

$$\rho = 0.0005 \cdot c + 0.7855 \ [\mathrm{g \cdot cm^{-3}}], \quad (3)$$

where
ρ .... density and
c .... volume concentration.

Very high correlation coefficient $R = 0.999$ was acquired. For pure diesel fuel, the density was 0.785 g·cm^{-3} and for pure RME (B100), it was 0.835 g·cm^{-3}. Density values of blend samples are listed in Tab. II below.

The influence of the RME concentration in diesel fuel with respect to dynamic viscosity was monitored. Once again it was proven that with increasing RME concentration, the dynamic viscosity dependence is nearly linear, as stated in (Borges *et al.*, 2011) and (Joshi and Pegg, 2007). The general formula has been used (2). After substitution, the relationship is as follows:

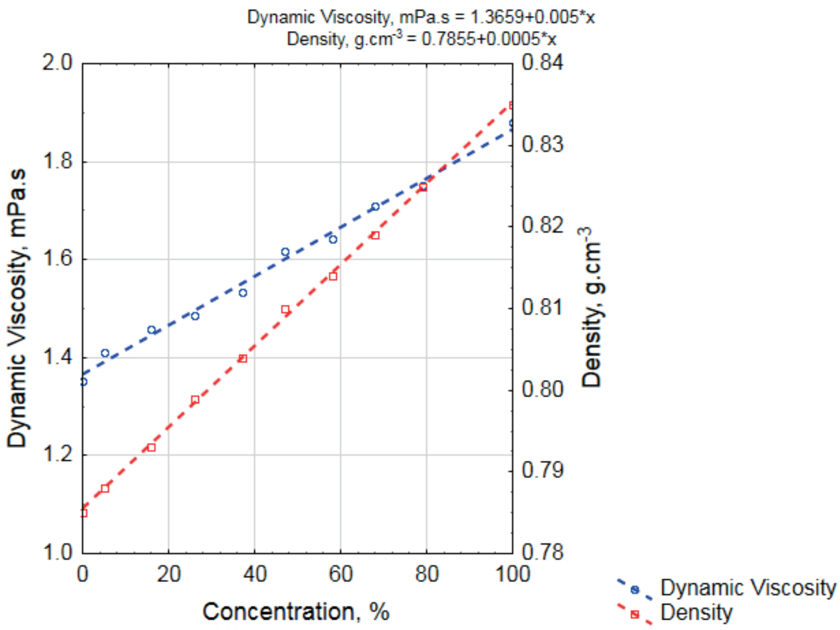
$$\eta = 0.005 \cdot c + 1.3659 \ [\mathrm{mPa \cdot s}], \quad (4)$$

where
η .... dynamic viscosity and
c .... volume concentration.

The correlation coefficient value in this group was as high as $R = 0.996$. For pure diesel fuel, the dynamic viscosity was 1.352 mPa·s. For pure RME (B100), the value was 1.881 mPa·s. Dynamic viscosity values of blend samples are listed in Tab. II below.

II: *Density and viscosity values of various blends of diesel fuel and RME*

No.	Diesel Fuel		RME		Temperature	Density	Dynamic Viscosity
	ml	%	ml	%	°C	g·cm^{-3}	mPa·s
1	1,000	100%	0	0%	40	0.785	1.352
2	947	95%	53	5%	40	0.788	1.412
3	842	84%	158	16%	40	0.793	1.459
4	737	74%	263	26%	40	0.799	1.487
5	632	63%	368	37%	40	0.804	1.534
6	526	53%	474	47%	40	0.810	1.617
7	421	42%	579	58%	40	0.814	1.643
8	316	32%	684	68%	40	0.819	1.709
9	210	21%	790	79%	40	0.825	1.751
10	0	0%	1,000	100%	40	0.835	1.881



2: *Effect of RME concentration in diesel fuel on its flow behaviour*

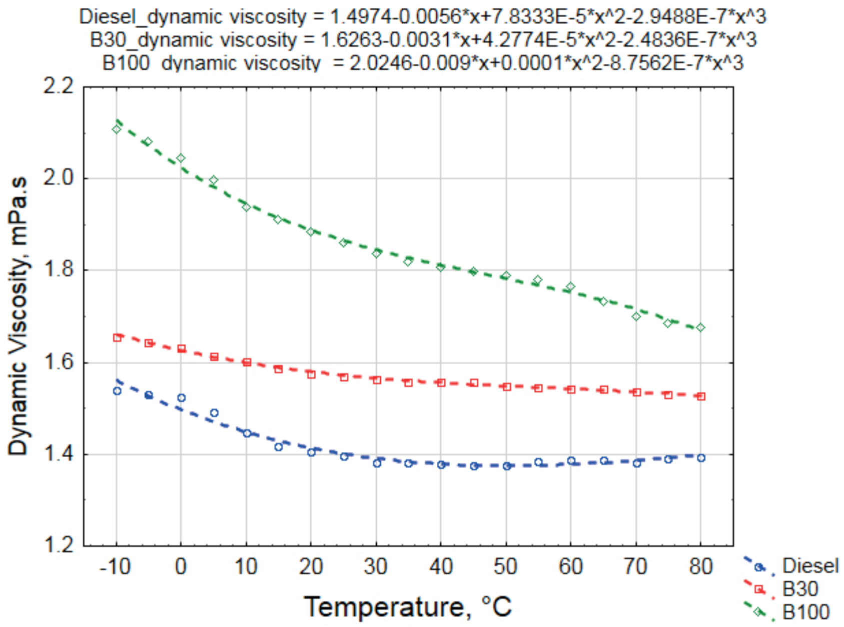
Values of density and dynamic viscosity provided source data for charts shown in Fig. 2. Individual values of the equation coefficients are included in the corresponding figures.

For three samples (pure diesel fuel, pure RME B100 and B30 blend) temperature dependence of dynamic viscosity and density was monitored. As expected and in accordance with the references (Maggi, 2006; Knothe and Steidley, 2007; Yuan *et al.*, 2009), higher temperature was connected to decrease of dynamic viscosity and density of samples, see Fig. 3 and Fig. 4. For the individual charts, mathematical models were constructed using 3rd polynomial degree (5) for the temperature dependence of dynamic viscosity and using 2nd polynomial degree (6) for the temperature dependence of the density. The general relationships were as follows:

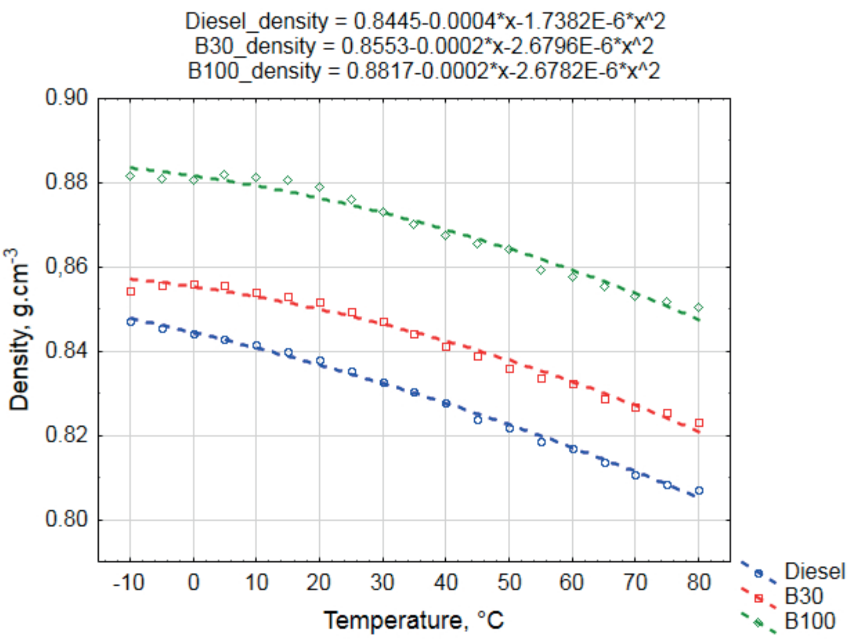
$$y = a_3 \cdot x^3 + a_2 \cdot x^2 + a_1 \cdot x + a_0 \quad (5)$$

and

$$y = a_2 \cdot x^2 + a_1 \cdot x + a_0. \quad (6)$$



3: *Dependence of temperature and dynamic viscosity*



4: *Dependence of temperature and density*

Individual values of the equation coefficients are included in the corresponding figures.

The *R* correlation coefficient showed high values in range from –0.796 to –0.974 (for 3rd polynomial degree) and in range from –0.976 to –0.994 (for 2nd polynomial degree).

CONCLUSION

Rapeseed oil methyl ester (RME) concentration in diesel fuel may affect its flow behaviour, i.e. dynamical viscosity and density. Several different blends of RME and diesel fuel were used for the experiment. All the samples were heated to comparative temperature of 40 °C (according to the ISO 8217 Standard). With increasing ratio of RME in diesel fuel, the density and dynamic viscosity of blends increased. The increase in density and dynamic viscosity were mathematically modeled using a linear function. The *R* correlation coefficient reached very high values of 0.999 (for density) and 0.996 (for dynamic viscosity).

For pure RME (B100), pure diesel fuel, and diesel fuel blend (B30), dependence of temperature and dynamic viscosity/density was monitored in range from –10 °C to 80 °C. Resulting dependence of temperature and dynamic viscosity/density was confirmed based on the assumptions and references. For these measurements, mathematical models were constructed using functions with the lowest number of degrees of freedom. Dependence of temperature and dynamic viscosity was modeled using 3rd polynomial degree. Dependence of temperature and density was modeled using 2nd polynomial degree. The *R* correlation coefficient reached very high values of –0.796, –0.948, –0.974 (for 3rd polynomial degree) and values of –0.994, –0.979, –0.976 (for 2nd polynomial degree).

Presented mathematical models can be used to predict the flow behaviour (density, dynamic viscosity, temperature/viscosity/density dependences) of RME, diesel fuel, and their blends.

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