# EFFECT OF THE RAPESEED OIL METHYL ESTER COMPONENT ON CONVENTIONAL DIESEL FUEL PROPERTIES[*]

## V. Kumbár, J. Votava

*Mendel University in Brno, Faculty of Agronomy, Brno, Czech Republic*

The effect of the rapeseed oil methyl ester (RME) component in diesel fuel was assessed. Dynamic viscosity and density of blends were particularly observed. Measurements were performed at standard constant temperature. Increasing ratio of RME in diesel fuel was reflected in increased density value and dynamic viscosity of the blend. In the case of pure RME, pure diesel fuel, and the blend of both, temperature dependence of dynamic viscosity and density was examined. Considerable temperature dependence of dynamic viscosity and density was found out and demonstrated for all three samples. This finding is in accordance with theoretical assumptions and literature data sources. Mathematical models were developed and tested. Temperature dependence of dynamic viscosity was modelled using the 3rd degree polynomial. Temperature dependence of density was modelled using the 2nd degree polynomial. The proposed models can be used for flow behaviour prediction of RME, diesel fuel, and their blends.

## 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 (G u i d o et al., 2013). Now (in accordance 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 (V l k , 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 the most widely used biofuels. These two liquid fuels can replace diesel fuel and petrol on a massive scale. They are applicable for engines of modern cars. Engines may run on unmodified (low biofuel content) or modified (high biofuel content) biofuels. In addition, these fuels can be distributed through the existing infrastructure (V l k , 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. In this case, we refer to the biofuel as rapeseed methyl ester (K r á l o v á , 2007).

From theoretical point of view, pure rapeseed oil methyl ester (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 (T s o l a k i s et al., 2007).

T i r a et al. (2014) state that as a result, it is more commonly used in a blend with conventional diesel

fuel. Dual fuel compression ignition engine has been proposed to reduce diesel engine regulated emissions (NO$_X$ and Soot) and also to allow the utilization of other non-traditional fuels in transportation, in order to improve fuel security and CO$_2$ emissions.

L a b e c k i et al. (2013) deal with the exhaust soot particles number size distributions obtained from the combustion of diesel and RME fuels. There were investigations in a high speed direct injection (HSDI) diesel engine for different engine operating conditions – fuel injection pressure, injection timing, exhaust gas recirculation (EGR), and engine load. An electrostatic mobility spectrometer (EMS) was used for analysing the exhaust soot particle number size distribution. Increasing the fuel injection pressure reduced the particle size and its number concentration in the accumulation mode under low and high load conditions, but an opposite trend was observed to the particle number concentration in the nucleation mode under higher load operation. The effect of fuel injection timings on the particle number concentration was not clear and consistent between diesel and RME fuels under low load operation. Under high load operation, the overall particle number concentration for RME decreased but for diesel only the nucleation mode decreased, while the accumulation mode remained unaltered when the fuel injection timing was retarded. The addition of EGR caused the particles to agglomerate and form larger size particles, which were observed mostly in the accumulation mode. Under most of the engine operating conditions RME emitted lower soot particle concentration than diesel under both nucleation and accumulation modes. The presence of oxygen in the fuel has the potential to lower the exhaust particle number concentration in diesel engines.

M i l l o et al. (2011) highlight that for part load operating conditions the average fuel consumption rose by 4% on a mass basis, at the same fuel conversion efficiency and CO$_2$ emissions. A notable increase of CO and HC emissions at low load could also be noticed, along with a significant NO$_x$ emissions decrease when using a specifically adjusted engine calibration, and a considerable smoke emission reduction.

The present paper addresses issues connected with the viscosity and density of RME, diesel fuel, and blends.

**MATERIAL AND METHODS**

RME, diesel fuel, and eight of their mutual blends with different mixing ratios were chosen for the experiment. Samples of a 1000 ml volume were used. A detailed description is given in Table 1.

Viscosity measurements were performed using the Anton Paar DV-3P rotational viscometer (Anton Paar, Graz, Austria). This device measures torque force required to overcome resistance of rotating cylinder or

Table 1. 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% |

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 the spindle. Measurement range for determination of material rheological properties can be adjusted by selecting the appropriate combination of the spindle and rotation speed. To obtain relevant results, it is necessary to know essential rheological properties of the given sample. Obviously, it is necessary to correctly classify the material prior to any testing (K u m b á r, S a b a l i a u s k a s, 2013).

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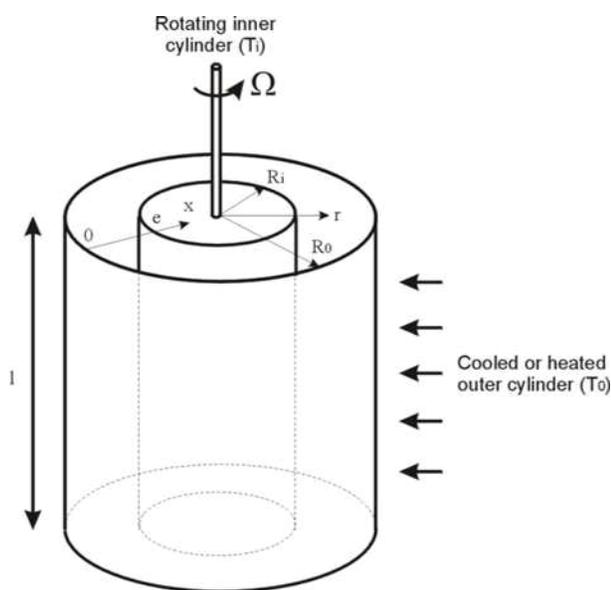


Fig. 1. Scheme of the measuring geometry

Table 2. 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 |

featuring very low viscosity. On the rotational viscometer the number of spindle revolutions was set to 100 per min 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. The presented procedure is in accordance with the references (K u m b á r , P o l c a r, 2012).

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 the measured sample:

$$\nu = \eta\, \rho^{-1} \ (\text{mm}^2\,\text{s}^{-1};\ \text{mPa s},\ \text{g cm}^{-3}) \qquad (1)$$

where:
$\nu$ = kinematic viscosity
$\eta$ = dynamic viscosity
$\rho$ = 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 I S O  8 2 1 7  S t a n d a r d .

A mathematical model was created using the software STATISTICA, Version 10. Accuracy (suitability) of the fitted functions was determined by the correlation coefficient $R$ (degree of significance $P < 0.05$).

**RESULTS**

Dynamic viscosity values of the blend samples are listed in Table 2. 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.

Temperature dependence dynamic viscosity of samples is shown in Fig. 3 and temperature dependence density of samples is shown in Fig. 4. Individual values of the equation coefficients are included in the corresponding figures.

**DISCUSSION**

Examination of RME concentration in diesel fuel revealed that with the increasing concentration the dependence of density of blend increased almost linear (Fig. 2). Expectedly, this result was in accordance with studies of A l p t e k i n ,  C a n a k c i  (2008) and R a m í r e z - V e r d u z c o  (2011). Then, a mathematical model was constructed. In the model, the following linear regression formula was used:

$$y = a_1\, x + a_0 \qquad (2)$$

after substitution, the formula reads as follows:
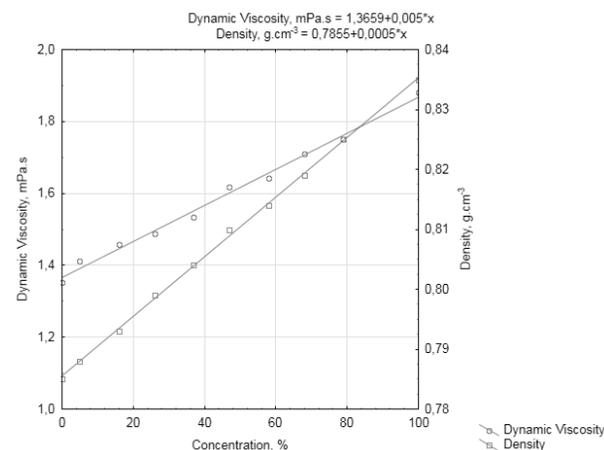


Fig. 2. Effect of RME concentration in diesel fuel on its flow behaviour

$\rho = 0.0005\ c + 0.7855\ (\text{g. cm}^{-3})$ (3)

where:

$\rho$ = density

$c$ = volume concentration

A 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 Table 2.

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 J o s h i ,   P e g g (2007) and B o r g e s  et al. (2011). The general formula (2) has been used. After substitution, the relationship is as follows:

$\eta = 0.005\ c + 1.3659\ (\text{mPa s})$ (4)

where:

$\eta$ = dynamic viscosity

$c$ = 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.

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 M a g g i (2006), K n o t h e ,   S t e i d l e y (2007), and Y u a n  et al. (2009), higher temperature was connected with the decrease dynamic viscosity and density of samples (Figs. 3, 4). For the individual charts, mathematical models were constructed using the 3$^{\text{rd}}$ polynomial degree (5) for the temperature dependence of dynamic viscosity and using the 2$^{\text{nd}}$ polynomial degree (6) for the temperature dependence of density. The general relationships were as follows:

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

and

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

The individual values of the equation coefficients are included in the corresponding figures. The $R$ correlation coefficient showed high values in the range from −0.796 to −0.974 (for the 3$^{\text{rd}}$ polynomial degree) and in the range from −0.976 to −0.994 (for the 2$^{\text{nd}}$ polynomial degree).

**CONCLUSION**

Rapeseed oil methyl ester (RME) component in diesel fuel may affect its flow behaviour, i.e. dynamic viscosity and density. Several different blends of RME and diesel fuel were used for the experiment. All the samples were heated in accordance with the I S O  8 2 1 7 S t a n d a r d to the comparative temperature of 40°C.

With the increasing ratio of RME in diesel fuel, the density and dynamic viscosity of the blends increased. The increase in density and dynamic viscosity was mathematically modelled 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), temperature dependence of dynamic viscosity and temperature dependence of density were monitored in the temperature range from −10°C to 80°C. Resulting temperature dependence of dynamic viscosity and temperature dependence of density were confirmed based on the assumptions and literature sources, but trends of result values attained different shapes for different fuels and their blends. For these measurements, mathematical models were constructed using functions with the lowest number of degrees of freedom. Dependence of temperature and dynamic viscosity was modelled using the 3$^{\text{rd}}$ polynomial degree. Dependence of temperature and density was modelled using the 2$^{\text{nd}}$ polynomial degree. The $R$ correlation coefficient reached very high values of −0.796, −0.948,
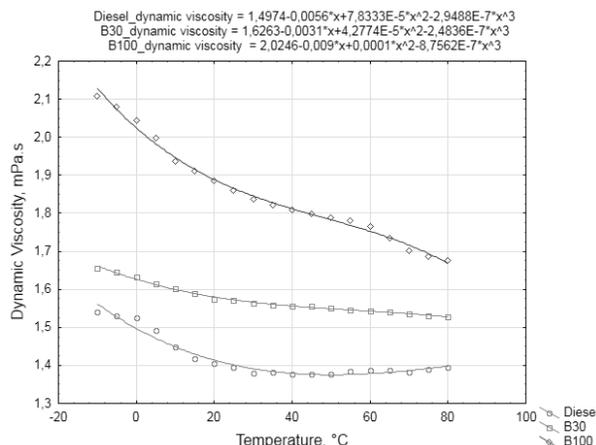


Fig. 3. Dependence of temperature and dynamic viscosity
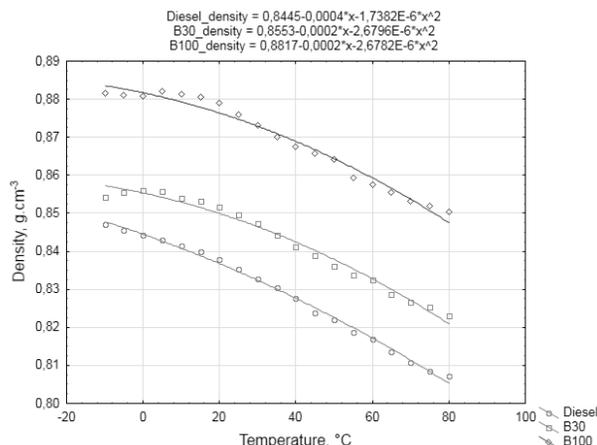


Fig. 4. Dependence of temperature and density

–0.974 (for the 3$^{rd}$ polynomial degree) and values of –0.994, –0.979, –0.976 (for the 2$^{nd}$ polynomial degree).

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

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*Corresponding Author:*

Ing. Vojtěch K u m b á r , Ph.D., Mendel University in Brno, Faculty of Agronomy, Department of Technology and Automobile Transport, Zemědělská 1, 613 00 Brno, Czech Republic, phone: +420 545 132 128, e-mail: vojtech.kumbar@mendelu.cz