

## Determination of the rheological properties of biofuels containing CME biocomponent

Similarly to diesel oil (B7), Biodiesla B100 CME dynamic viscosity at positive temperatures in principle increases with decreasing temperature. Having exceeded 263K, it begins to increase rapidly. The dynamic viscosity for B100 CME at 253 K was 204 mPa·s, for B75 CME – 118 mPa·s, for B50 CME – 77 mPa·s and for B20 CME – 42 mPa·s. The study has shown that B100 CME cannot be used in practice as a pure fuel without a package of viscosity-lowering additives. At the same time, the viscosity values for B5 and B20 biofuels, in particular at positive temperatures, are close to the viscosity of diesel fuel. Under such conditions one can safely use B7 and B20 biofuels in compression-ignition engines, even in those with a state-of-the-art injection apparatus.

Key words: diesel engine ZS, Biodiesel, biofuel, CME (Corn Methyl Esters), corn oil, dynamic viscosity

### Określenie własności reologicznych biopaliw zawierających biokomponent CME

Lepkość dynamiczna biodiesla B100 CME w zakresie dodatnich temperatur w zasadzie rośnie wraz z obniżaniem temperatury, podobnie jak oleju napędowego (B7). Natomiast po przekroczeniu 263 K zaczyna gwałtownie rosnać. Lepkość dynamiczna w temperaturze 253 K – B100 CME wynosiła 204 mPa·s, B75 CME – 118 mPa·s, B50 CME – 77 mPa·s, natomiast B20 CME – 42 mPa·s. Przeprowadzone badania pokazały, że w praktyce B100 CME nie może być stosowane jako samoistne paliwo, bez zastosowania pakietu dodatków obniżających lepkość. Natomiast dla biopaliw typu B7 i B20 wartości lepkości szczególnie w zakresie dodatnich temperatur są zbliżone do lepkości oleju napędowego. W takich warunkach bez obaw można używać B7 i B20 do zasilania silników z zapłonem samoczynnym nawet posiadających nowoczesną aparaturę wtryskową.

Słowa kluczowe: silnik z zapłonem samoczynnym ZS, Biodiesel, biopaliwo, CME (estry metylowe oleju kukurydzianego), olej kukurydziany, lepkość dynamiczna

### 1. Introduction

Quality standards PN-EN 590:2006 for diesel fuel and EN ISO3104 for FAME fuel determine only kinematic viscosity. No obligatory norm has been introduced so far for determining dynamic viscosity. Kinematic viscosity is a parameter describing the resistance of fluid flow due to gravity forces. In order to determine kinematic viscosity the time flow for constant fluid volume through a capillary tube of a standard viscosimeter under the influence of gravity forces is measured, under repeatable conditions and at known, strictly controlled temperature. The value of kinematic viscosity is computed by multiplying the flow time by viscosimeter standardization constant. However, the norm allows three groups of viscosimeters, so the methods of measurements may differ from the described above depending on the kind and range of the tested fluid viscosity [6].

Analysis of the subject literature shows various values of RME kinematic viscosity, which according to some authors at the temperature of e.g. 297K ranged from 6 [3] to 2000 [mPas] [4]. However, it seems that the scatter of results was not so wide but was rather due to a measurement error or applica-

tion of little precise methods. Therefore even a small mistake during measurement may cause a considerable scatter of obtained kinematic viscosity values. Additionally such error may be multiplied at dynamic viscosity determination [13,14,15].

In recent years a rapid development of injection apparatus based on pump-injectors or common rail has been observed, where very high pressure occurs. In this situation it is most important to determine the fluid flow resistance under dynamic, not static conditions. It is the more important when type “B” fuels with biocomponent supplement of higher viscosity are used for ZS engine feeding. Therefore dynamic, not kinematic viscosity should be determined most precisely. So far dynamic viscosity has not been determined separately, only obtained from kinematic viscosity. It was due to a lack of proper tools which were relatively expensive. However, a dynamic development of rheometers in recent years, particularly dynamic types, allowed for a most precise determination of dynamic viscosity. Moreover, for a better assessment of fuel mechanical properties the influence of many rheological

parameters on the behavior of fuels or biofuels may be also tested.

The advantages of using rotational rheometers for viscosity determination comprise: small volume of fuel sample (about 50 ml is enough), full automatic and computerized measurements, possibility of testing both viscous and elastic properties, possible investigation of tixotropy and antitixotropy phenomena.

Dynamic viscosity is a measure of fluid's resistance to flow or fluid deformation - Polish standard PN-EN ISO 3104. It also affects the injection course, stream range and fuel spraying in the engine combustion chamber. It influences lubrication properties, which is particularly important in the case of rotational injection pumps because in the pumps of this type the pump elements are lubricated with diesel oil. It may be the reason why one sometimes encounters the opinion that small viscosity and resulting good flow properties are more important for the engine start up than the cetane number [2, 3, 5, 8]. There is also a strict relationship between viscosity, temperature and shearing rate.

There is a serious problem concerning an excessive viscosity of some biofuels, which in recent years has become one of the key issues. It is primarily connected with the use of injection apparatus, which supplies fuel to the engine at dynamic

pressure reaching 2600 bar. Therefore even a slight increase in this parameter may negatively affect the work of injection apparatus. The fact that biofuels would enter the fuel markets was known in 1997, so the manufacturers should adjust the injection systems also for the fuels with a 20 to 40% higher viscosity. Biodiesel quality also poses a problem. It turns out that usually FAME has more products of incomplete conversion to esters of oil obtained through transesterification process. EN-14214 standard for FAME Biodiesel fuel states the maximum allowable amount of monoacyloglycerols in fuels as 0.8%, whereas diacylglyceryl ethers only 0.2% (m/m). Another problem is wrong separation of ester from glycerin phase, since even trace amounts of glycerin phase left over lead to a considerable increase in viscosity. As results from the Author's own research, viscosity of properly separated glycerin phase obtained after rapeseed oil methanolysis at 20°C is about 940 [mPas], whereas in diesel fuel about 8[mPas], RME esters about 13 [mPas], whereas rapeseed oil about 70 [mPas]. It results from the data given above that at 20°C oil viscosity is 5,5 times higher and viscosity of glycerin phase by over 72 times higher than RME viscosity [7].

## 2. Methods of research

Measuring set with two coaxial cylinders was applied in the rheometer. Beside the cone/plate viscometer it is one of the most precise devices for measuring dynamic viscosity of fuels and biofuels.

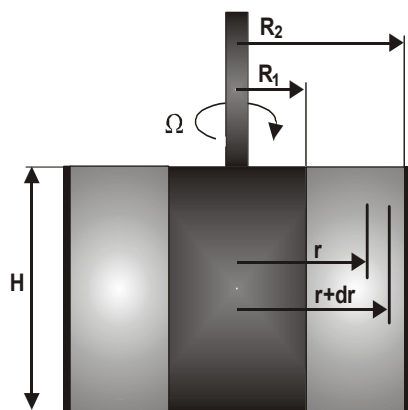


Fig. 1. Measuring set with coaxial cylinders

Figure 1 shows the schematic diagram of the measuring set with marked parameters which served to formulate the main relationships: for tangent force, oscillating torque, shearing force and dynamic viscosity.

Assuming that the tested sample has the height  $H$ , tangent force in the fluid at the distance  $r$  from the rotation axis may be expressed by the formula 1. Considering rotating frequency of the spinning element and outer diameter of the spinning element  $R_1$  and inner diameter of cylinder sleeve  $R_2$  filled with the tested fluid, we may derive formula 2 describing the relationship for shearing force. If oscillating torque caused by tangent force is equal it may be generally written as  $M = F \cdot r$ . On the other hand for the set applied in the rheometer, i.e. measuring set with coaxial cylinders, the oscillating torque may be shown by formula 3. Tangent friction forces transferred by the fluid to the inner cylinder cause the described oscillating torque  $M$ . Considering the above mentioned assumptions the formula for dynamic viscosity using coaxial cylinder set may be described using formula 4.

$$F_r = 2\pi r H \tau_r \quad (1)$$

$$\dot{\gamma} = \frac{2\Omega}{1 - \frac{R_1^2}{R_2^2}} \quad (2)$$

$$M = \frac{4\pi\eta H \Omega}{\frac{1}{R_1^2} - \frac{1}{R_2^2}} \quad (3)$$

$$\eta = \frac{1}{4\pi H} \left( \frac{1}{R_1^2} - \frac{1}{R_2^2} \right) \frac{M}{\Omega} \quad (4)$$

where:

$\Omega$  - rotating frequency of the spinning element

$M$  - oscillating torque acting on spinning element axis

$H$  - height of biofuel sample

$r$  - distance from rotation axis

$R_1$  - outer radius

$R_2$  - inner radius of cylinder sleeve

### 3. Aim and scope of research

The research aimed at determining the effect of temperature on dynamic viscosity of Biodiesel SBME type biofuels. Three kinds of fuels were prepared: ON (B7), B20, B50, B75 and B100. The value attached to "B" letter denotes volumetric proportion of SBME (methyl esters obtained from soya bean's oil) in the mixture with fuel oil.

These biofuels were selected because of the current attempts to create an alternative to Biodiesel obtained from CME corn oil. Currently in Poland, it is possible to purchase sunflower oil at a price competitive to corn oil.

These biofuel types were selected because, currently passed act on biocomponents and biofuels allows to use up to 7% (v/v) of biocomponent supplements in fuels without the obligatory relevant information for the buyer about the supplement. In accordance with the National Index Target, in 2015 in Poland we needed to consume on average 7.1% of biofuels and/or bio-components in relation to the total fuel consumption, calculating in energy terms.

The second chosen biofuel was B20 since by 2020 a mean biocomponent share in the total bal-

ance of fuels consumed by the transport will reach at least 20%. The third biofuel selected for comparative testing was B100, or pure CME ester. In addition, for comparison purposes tests were performed on the commercial diesel and RME fuels from a service station being part of Bliska service station chain.

The basic fuel for type B75, B50 and B20 biofuels was the commercial VERVA ON fuel oil manufactured by PKN ORLEN S.A. company. The research determined the variability of dynamic viscosity within the temperature range from 253 to 323K. The range of temperatures was assumed because due to the applied thermostatic bath it was impossible to lower the sample temperature below -293K. On the other hand raising the upper temperature above 323K was considered unnecessary because it does not generally affect a change of dynamic viscosity. In the initial part of the test shearing rate of the rheometer spindle was constant 1000 [s<sup>-1</sup>].

### 4. Characterization of measuring stand

The main device used at the measuring stand was ReolabQC rheometer manufactured by a German Anton Paar GmbH company (Fig. 2). The rheometer is a device designed for determining mechanical and rheological parameters of fluids and fuels. The device measures among others dynamic viscosity, surface tension, shearing forces, shearing rate, shearing tension, etc. The rheometer

is also equipped with a temperature sensor and integrated system of time measurement. In order to determine the effect of temperature on the above mentioned parameters, the rheometer used at the measuring stand was additionally equipped with thermostatic bath made by an Austrian Grant company. The results of research using measuring system of the viscosimeter were sent to a computer and saved there to be subsequently processed using RHEOPLUS/32 V3.0. Figure 3 presents the algorithm of the ReolabQC rheometer external control.



Fig. 2. The researchers post was furnished with a reometer and tub thermostats

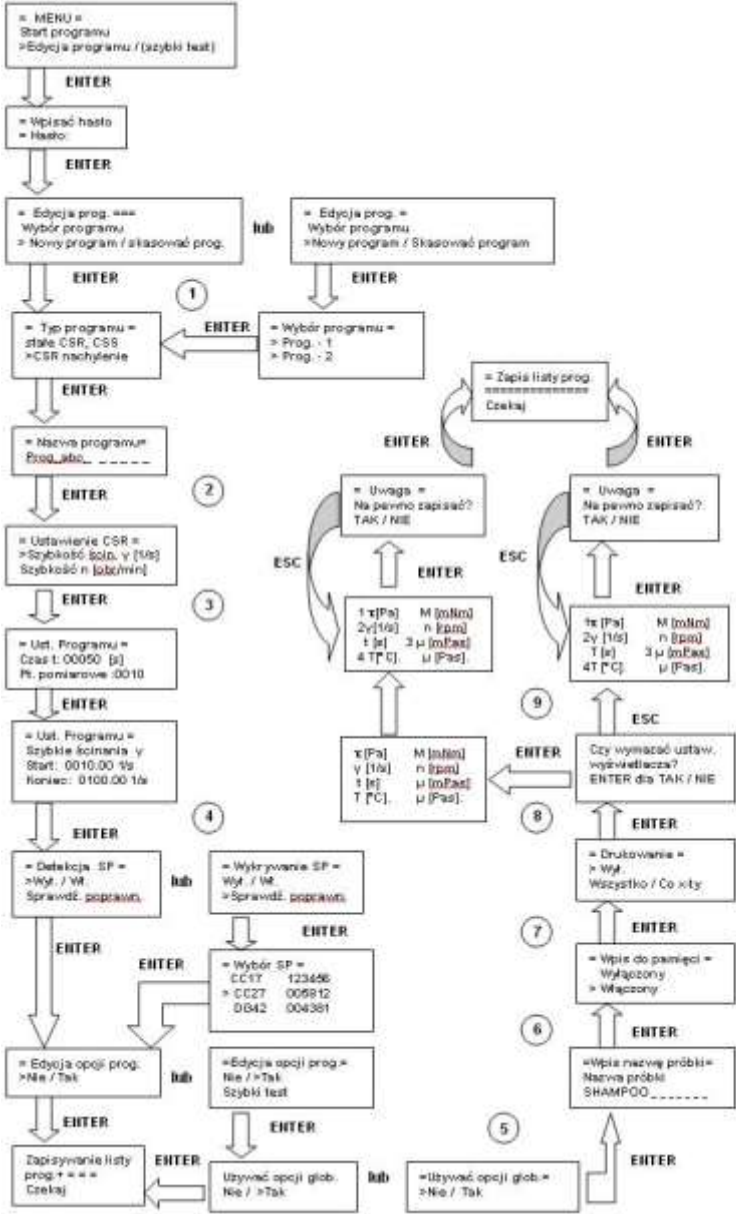


Fig. 3. The algorithmic work schemata is using the reometer ReolabQC

## 5. Results and discussion

Figures 4 through 5 show the results of research on determining the effect of temperature on dynamic viscosity.

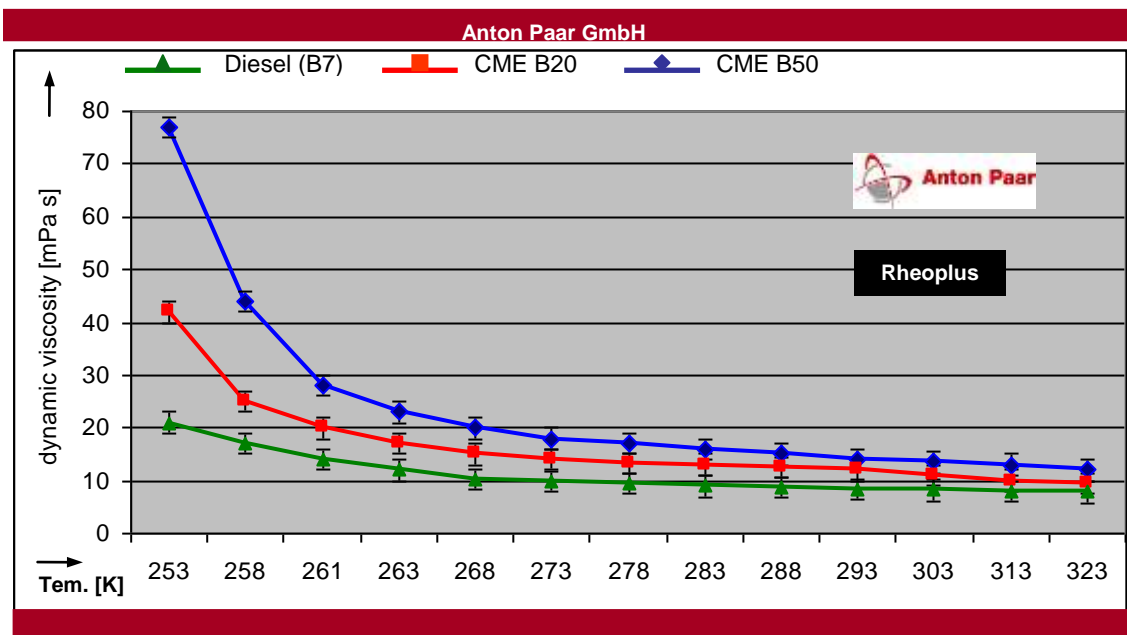


Fig. 4. Diagram of B50, B20 CME and Diesel (B7) dynamic viscosity dependence in the function of temperature

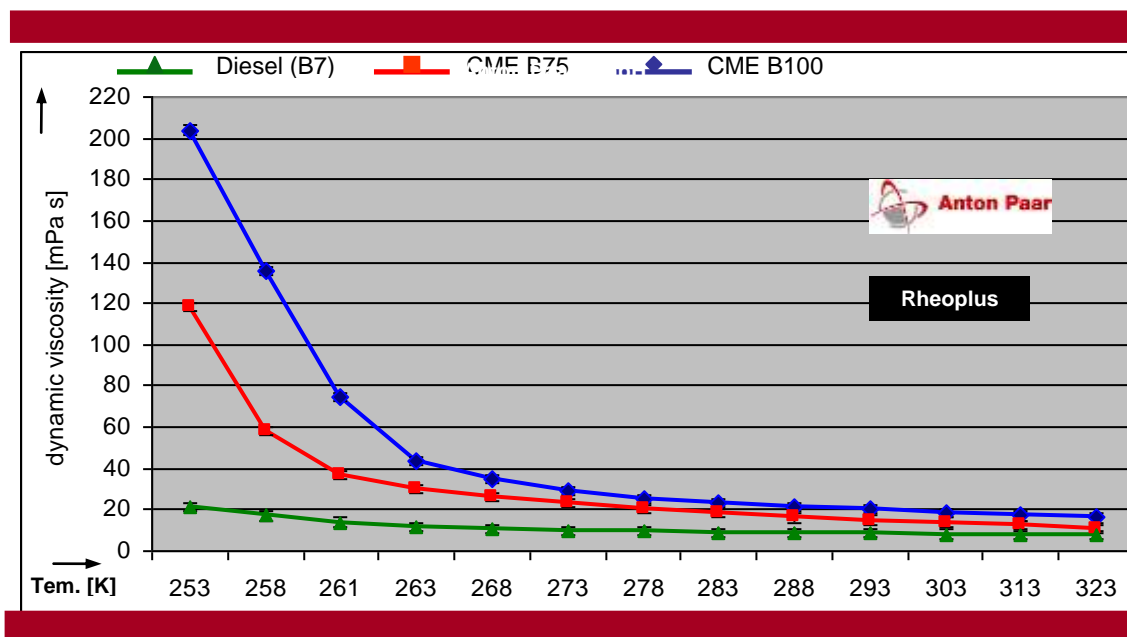


Fig. 5. Diagram of B100, B75 CME and Diesel (B7) dynamic viscosity dependence in the function of temperature

## 6. Conclusions

Dynamic viscosity of B100 CME Biodiesel in the temperature range from 323 to 253K assumes the values from c.a. 16 to 204 [mPa·s]. Dynamic viscosity of B75 CME Biodiesel at 323 was 12 [mPa·s]. When the temperature was decreasing its value was increasing and at 253K reached 118 [mPa·s]. Dynamic viscosity of B50 CME Biodiesel in the temperature range from 323 to 253K assumes the values from c.a. 11 to

77 [mPa·s]. Dynamic viscosity for B20 CME Biodiesel at 323K was 9,5 [mPa·s], but with cooling fuel sample it was growing to reach 42 [mPa·s] at 253K. Dynamic viscosity of diesel oil (B7), in the temperature range from 323 to 253K assumes the values from c.a. 7,8 to 21 [mPa·s]. Conducted research demonstrated that dynamic viscosity of "B" biofuels is considerably affected by the temperature. Therefore, for a

better assessment of the effect of engine diesel feeding with biofuels on the durability and reliability of the injection apparatus, not kinematic but dynamic viscosity should be considered. It is important because the changes of dynamic viscosity illustrate the actual changes of the flow resistance accompanying engine feeding with biofuels and biocomponents. Currently conducted research focuses on introduction of a proper

standard for determining dynamic viscosity of fuels and biofuels. There are standards for rotation rheometers by means of which dynamic viscosity and other parameters, including surface tension, shearing forces, shearing rate or shearing tension may be highly precisely determined, which will make possible a better analysis of rheological properties of fuels and biofuels.

### Nomenclature/Skróty i oznaczenia

CME Corn Methyl Esters/estry metylowe oleju kukurydzianego

RME Rapeseed Methyl Esters/estry metylowe oleju rzepakowego

FAME Fatty Acid Methyl Esters/estry metylowe kwasów tłuszczowych

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