Determination of the Rheological Properties of Biofuels Containing SBME Biocomponent

Grzegorz Wcisło

Faculty of Production Engineering and Power Technologies
University of Agriculture in Krakow, Poland
email: grzegorz.wcislo@ur.krakow.pl

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Summary. Similarly to diesel oil (B7), Biodiesla B100 SBME dynamic viscosity at positive temperatures in principle increases with decreasing temperature. Having exceeded -10ºC, it begins to increase rapidly. The dynamic viscosity for B100 SBME at -20°C was 173 mPas, for B50 SBME – 67mPas and for B20 SBME – 67mPas. The study has shown that B100 SBME 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, Biodiesel, biofuel, SFME, dynamic viscosity, shearing rate.

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, 17].

Analysis of the subject literature shows various values of RME kinematic viscosity, which according to some authors at the temperature of e.g. 20ºC 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 application 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 [13,14,15,16].

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 behaviour of fuels or biofuels may be also tested.

The advantages of using rotational rheometers for viscosity determination comprise: small volume of fuel sample (about 50ml 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 2600bar. 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 glycerine phase, since even trace amounts of glycerine phase left over lead to a considerable increase in viscosity. As results from he Author's own research, viscosity of properly separated glycerine phase obtained after rapeseed oil methanolysis at 20ºC 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 20ºC oil viscosity is 5,5 times higher and viscosity of glycerine phase by over 72 times higher than RME viscosity [7].

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. 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.

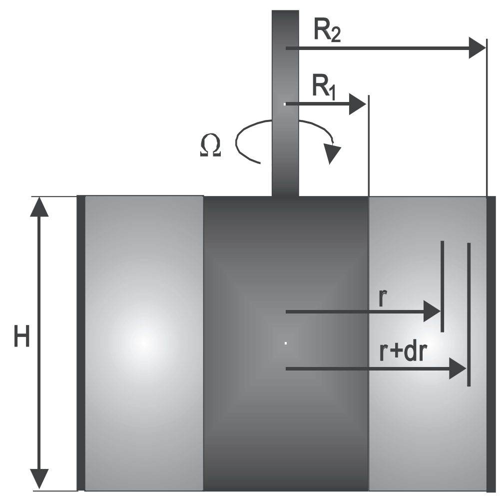

Fig. 1. Measuring set with coaxial cylinders

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.

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

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

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

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

where:
Ω – 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

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 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 SBME soya bean oil. Currently in Poland, it is possible to purchase sunflower oil at a price competitive to soya bean 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 2014 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 balance of fuels consumed by the transport will reach at least 20%. The third biofuel selected for comapartive testing was B100, or pure SBME 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 B50 and B20 biofeuls 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 -20 to 50ºC. The range of temperatures was assumed because due to the applied thermostatic bath it was impossible to lower the sample temperature below -20ºC. On the other hand raising the upper temperature above 50ºC 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 1050 [s^{-1}].

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 devise 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.

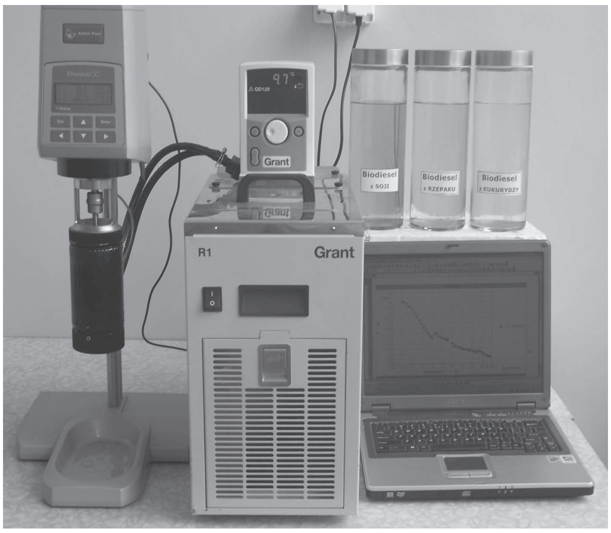

Fig. 2. The researchers post was furbished with a reometer and tub thermostats

The rheometer was equipped with internal memory and the system for research programme generation. Figure 3 presents the algorithm of the ReolabQC rheometer external control. The rheometer may be externally controlled by a computer which allows for creating and editing measuring programmes, which makes possible optional and multiple parameter setting and saving them without the necessity of deleting.

RESULTS AND DISCUSSION

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

CONCLUSIONS

Dynamic viscosity of B100 SBME Biodiesel in the temperature range from 50 to -20ºC assumes the values from c.a. 10 to 173 [mPas]. Dynamic viscosity of B50 SBME Biodiesel at 50ºC was 9[mPas]. When the temperature was decreasing its value was increasing and at -20ºC reached 67[mPas]. Dynamic viscosity for B20 SBME Biodiesel at 30ºC was 8,5[mPas], but with cooling fuel sample it was growing to reach 35[mPas] at -20ºC. Dynamic viscosity of diesel oil (B7), in the temperature range from 50 to -20ºC assumes the values from c.a. 7,8 to 17 [mPas]. Conducted research demnstrated that dynamic viscosity of "B" biofuels is considerably affected by the temperature. Therefore, for a better assessment of the effect of SE engine 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.

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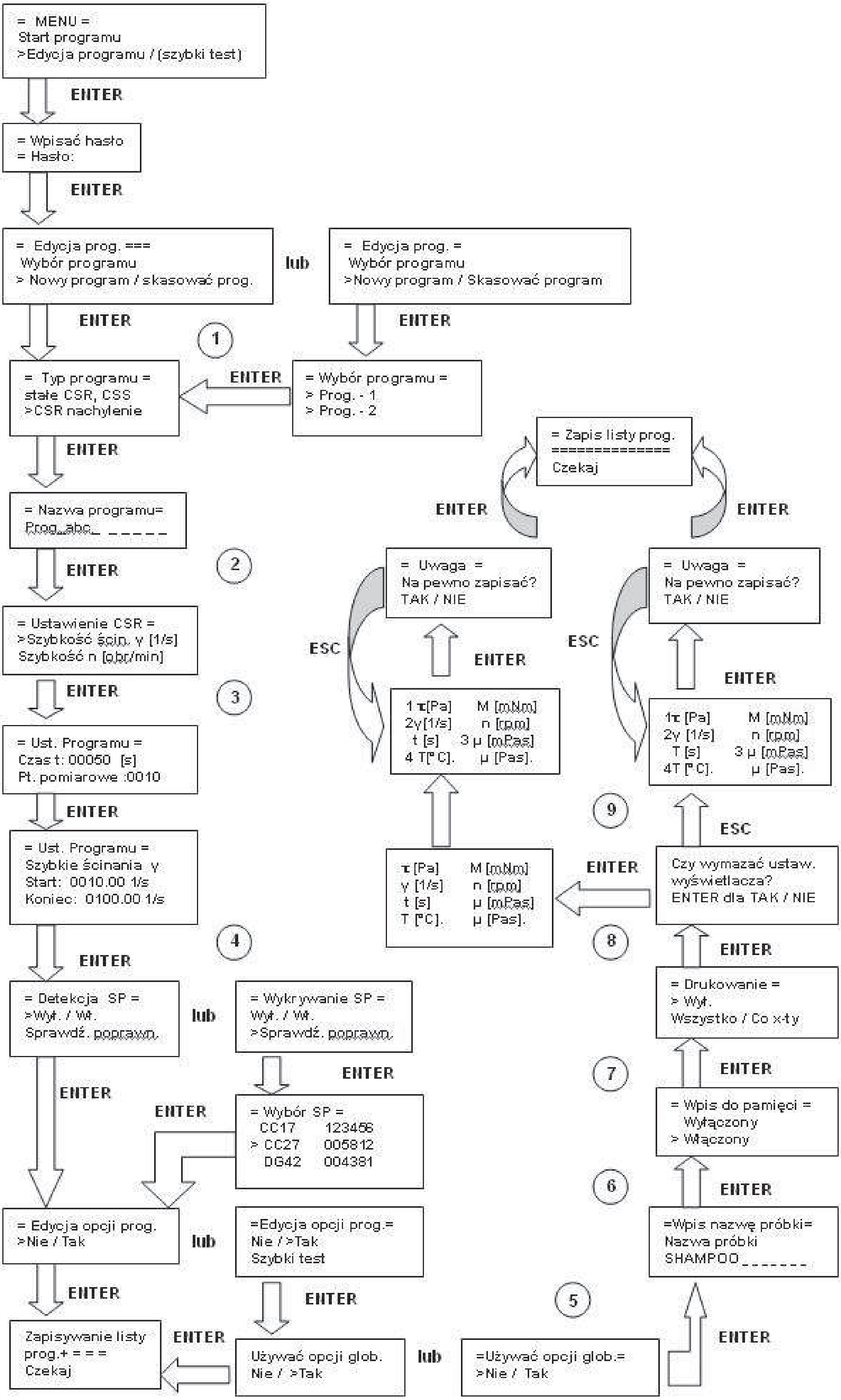

Fig. 3. The algorithmic work schemata is using the reometer ReolabQC

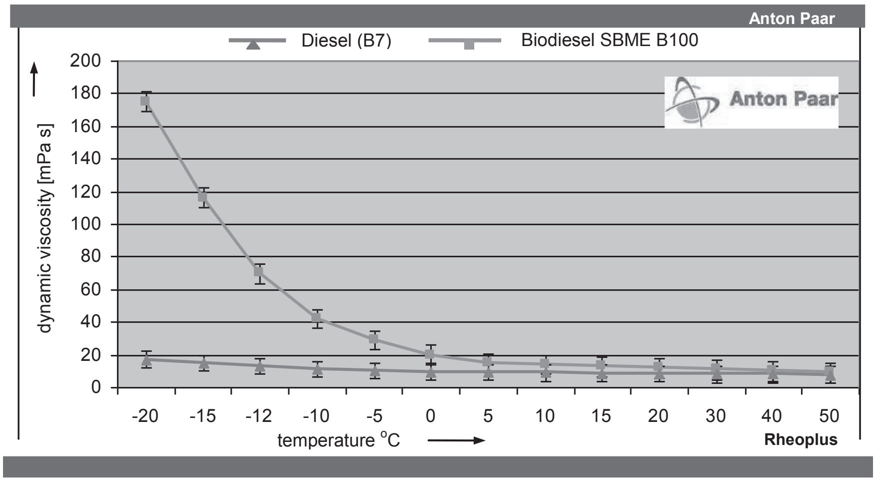

Fig. 4. Diagram of B100 SBME and Diesel (B7) dynamic viscosity dependence in the function of temperature

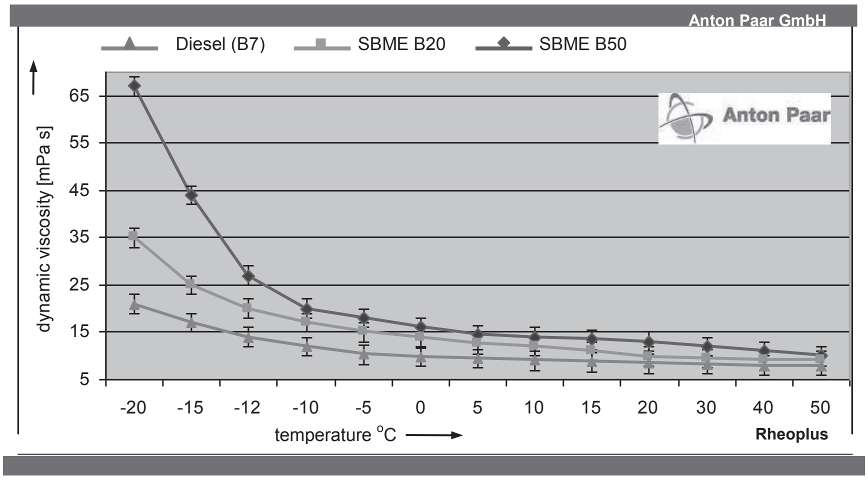

Fig. 5. Diagram of B50, B20 SBME and Diesel (B7) dynamic viscosity dependence in the function of temperature

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OKREŚLENIE WŁASNOŚCI REOLOGICZNYCH BIOPALIW ZAWIERAJĄCYCH BIOKOMPONENT SBME

Streszczenie. Lepkość dynamiczna Biodiesla B100 SBME w zakresie dodatnich temperatur w zasadzie rośnie wraz z obniżaniem temperatury, podobnie jak oleju napędowego (B7). Natomiast po przekroczeniu -10oC zaczyna gwałtownie rosnąć. Lepkość dynamiczna w temperaturze -20oC B100 SBME wynosiła 173mPas, B50 SBME 67mPas, natomiast B50 SBME 35mPa. Przeprowadzone badania pokazały, że w praktyce B100 CSME nie może być stosowane jako samoistne paliwo, bez zastosowania pakietu dodatków obniżających lepkość.Natomiast dla biopaliw typu B5 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 samoczynnych nawet posiadających nowoczesną aparaturę wtryskową.

Słowa kluczowe: silnik wysokoprężny, Biodiesel, biopaliwo, SFME, lepkość dynamiczna, szybkość ścinania.