

## Determining the effect of the addition of bio-components AME on the rheological properties of biofuels

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**Summary.** The aim of the study was to determine the effect of FAME bio-components on the dynamic viscosity of biofuels in temperature range of from  $-20$  to  $50^{\circ}\text{C}$ . Six kinds of fuels have been prepared: B0 (clear Fuel Diesel), B20, B40, B60, B80 and B100. The value attached to “B” letter denotes volumetric proportion of AME (methyl esters obtained from animal’s fat) in the mixture with fuel oil. The main device used at the measuring stand was ReolabQC rheometer manufactured by a German Anton Paar GmbH company. Dynamic viscosity especially grew rapidly after cooling biofuels to temperatures below  $0^{\circ}\text{C}$ . Dynamic viscosity AME biofuels produced from pure animal fat in a temperature range of  $50$  to  $-20^{\circ}\text{C}$  has a value of c.a.  $15$  to  $150$  [mPa·s]. Dynamic viscosity of Biofuel AME produced from animal fat consumed it was on average higher by about  $5$  to  $10$  [mPa·s] of AME manufactured from pure fat.

**Key words:** Biodiesel, AME - Animal Fat Methyl Esters, diesel engine, dynamic viscosity, shearing rate

### INTRODUCTION

Among basic parameters determining particularly biofuel usefulness for feeding self-ignition engines are viscosity and density. From the above mentioned parameters, both kinematic and dynamic viscosity are characterized by a relatively big amplitude of parameter changes in the temperature function. 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. Analysis of the subject literature shows various values of RME kinematic viscosity, which according to some authors at the temperature of e.g.  $20^{\circ}\text{C}$  ranged from  $6$  to  $2000$  [mPas] [1, 9, 11]. 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 self-ignition 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 [5, 6].

The advantages of using rotational rheometers for viscosity determination comprise: small volume of fuel sample (about  $50\text{ml}$  is enough), full automatic and computerized measurements, possibility of testing both viscous and elastic properties, possible investigation of thixotropy and antithixotropy 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, 4]. There is also a strict relationship between viscosity, temperature and shearing rate. 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 the Author's own research, viscosity of properly separated glycerine 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 glycerine phase by over 72 times higher than RME viscosity [10].

#### 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 [7, 8]. 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.

#### AIM AND SCOPE OF RESEARCH

The research aimed at determining the effect of temperature on dynamic viscosity of Biodiesel AME type biofuels. Six kinds of fuels were prepared: B0 (clear Fuel Diesel), B20, B40, B60, B80 and B100. The value attached to "B" letter denotes volumetric proportion of AME (methyl esters obtained from animal fat) in the mixture with fuel oil. These biofuel types were selected because, currently passed act on biocomponents and biofuels allows to use of biocomponent supplements in fuels without the obligatory relevant information for the buyer about the supplement. The basic fuel for type B20

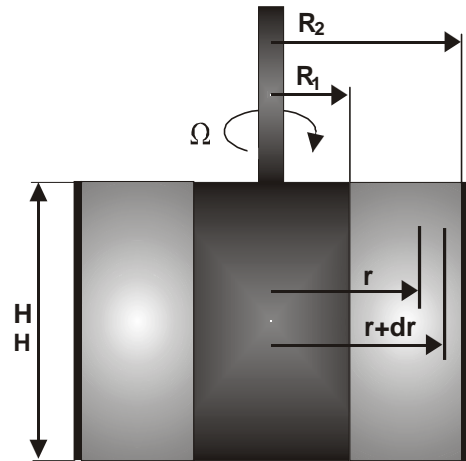


Fig. 1. Measuring set with coaxial cylinders

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

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

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

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

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

and B80 biofuels was the commercial Eurodiesel fuel oil manufactured by LOTOS S.A. company. The research determined the variability of dynamic viscosity within the temperature range from -20 to 50°C. The range of temperatures was assumed because due to the applied thermostatic bath it was impossible to lower the sample temperature below -20°C. On the other hand raising the upper temperature above 50°C was considered unnecessary because it does not generally affect a change of dynamic viscosity. In the test shearing rate of the rheometer spindle was constant 1050 [s<sup>-1</sup>].

CHARACTERIZATION OF MEASURING STAND

The main device used at the measuring stand was ReolabQC rheometer manufactured by the German Anton Paar GmbH company (Fig. 2).



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

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.

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 programs, which makes possible optional and multiple parameter setting and saving them without the necessity of deleting.

RESULTS AND DISCUSSION

Figures 4 and 5 show the results of research on determining the effect of temperature on dynamic viscosity. Figure 4 is a diagram showing the effect of the addition of bio-components of the AME produced pure animal fat on the dynamic viscosity with temperature. The graph shows the results of six studies of fuel, pure AME (B100), diesel fuel and biofuels B20, B40, B60 and B80.

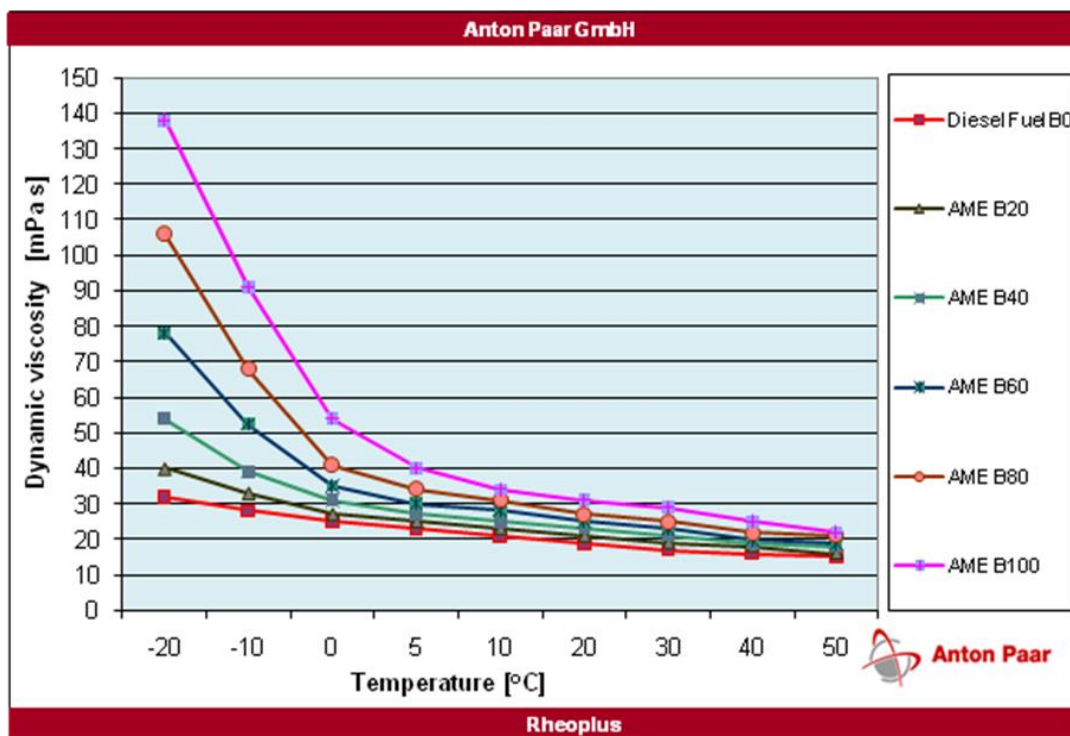


Fig. 4. Dynamic viscosity of biofuel containing AME made of pure fat as a function of temperature

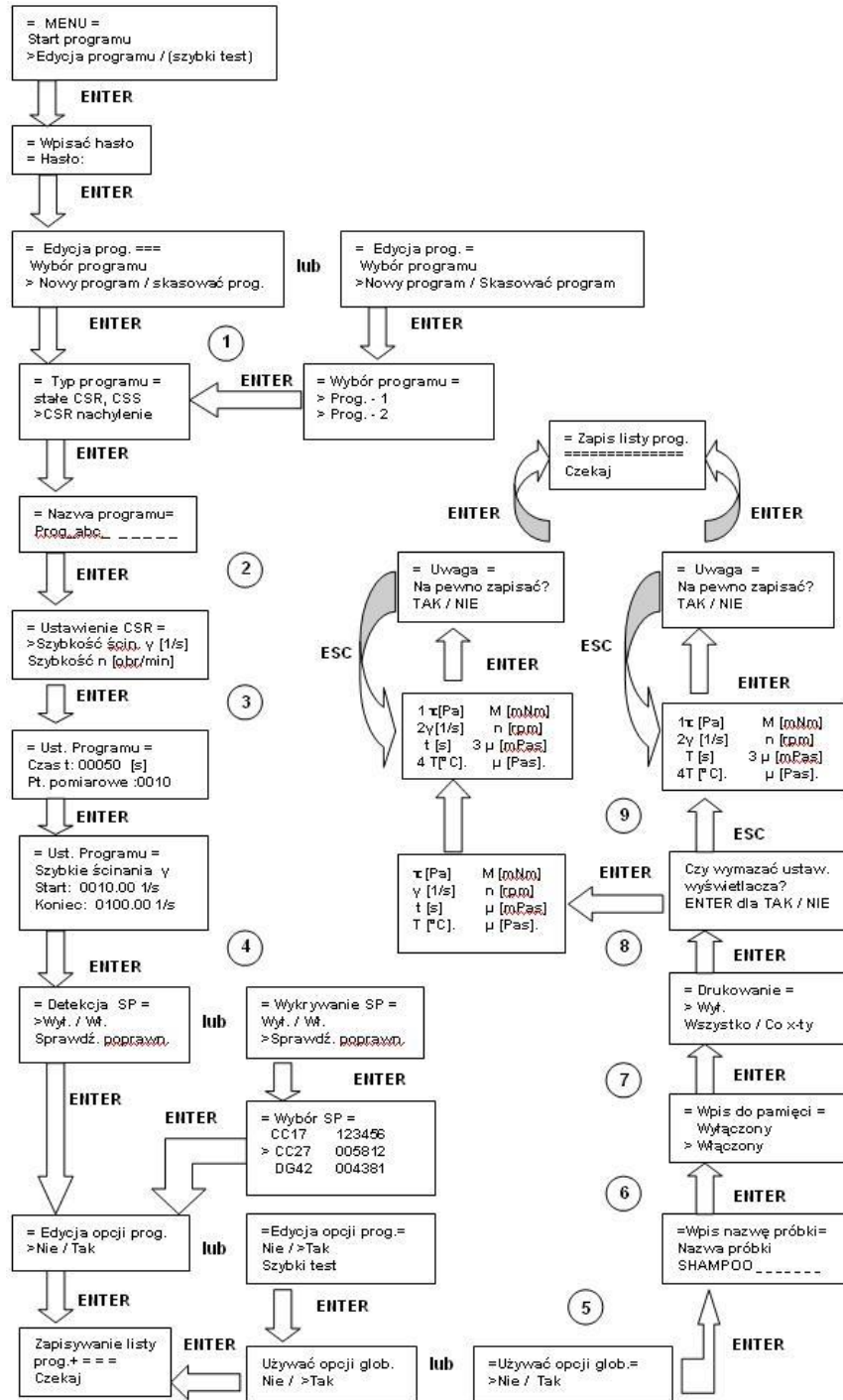


Fig. 3. The algorithmic work schemata is using the reometer ReolabQC

Dynamic viscosity especially grew rapidly after cooling biofuels to temperatures below 0°C. Dynamic viscosity B100 AME Biodiesel produced from pure animal fat in a temperature range of from 50 to -20°C has a value of c.a. 22 to 138 [mPa·s]. Dynamic viscosity of B80 AME biofuels at 50°C was 21[mPa·s]. When the temperature was decreasing its value was increasing and at -20°C reached 106[mPa·s]. Dynamic viscosity of B60 AME biofuels at 50°C was 19[mPa·s]. When the temperature was decreasing its value was increasing and

at -20°C reached 54[mPa·s]. Dynamic viscosity of B40 AME biofuels at 50°C was 18[mPa·s]. When the temperature was decreasing its value was increasing and at -20°C reached 78[mPa·s]. For comparison, the dynamic viscosity Fuel Diesel in a temperature range of from 50 to -20°C has a value of c.a. 15 to 32 [mPa·s].

Figure 5 is a diagram showing the effect of the addition of bio-components of the AME produced waste (used for frying) animal fat on the dynamic viscosity with temperature. The graph shows the results of six studies of

fuel, pure AME (B100), diesel fuel and biofuels B20, B40, B60 and B80. For the B100 AME biofuel at 50°C viscosity was 25[mPa·s], but reached the value of 148[mPa·s] when the temperature fell to -20°C. Viscosity value of 23[mPa·s] was obtained for B80 biofuel at 50°C, but it was growing when the fuel sample was cooling and

reached 112[mPa·s] at -15°C. Dynamic viscosity of other biofuels B40 to B80 containing biocomponent AME waste produced from animal fat was on average higher by about 5 to 10 [mPa·s] AME biocomponent containing biofuels produced from pure fat.

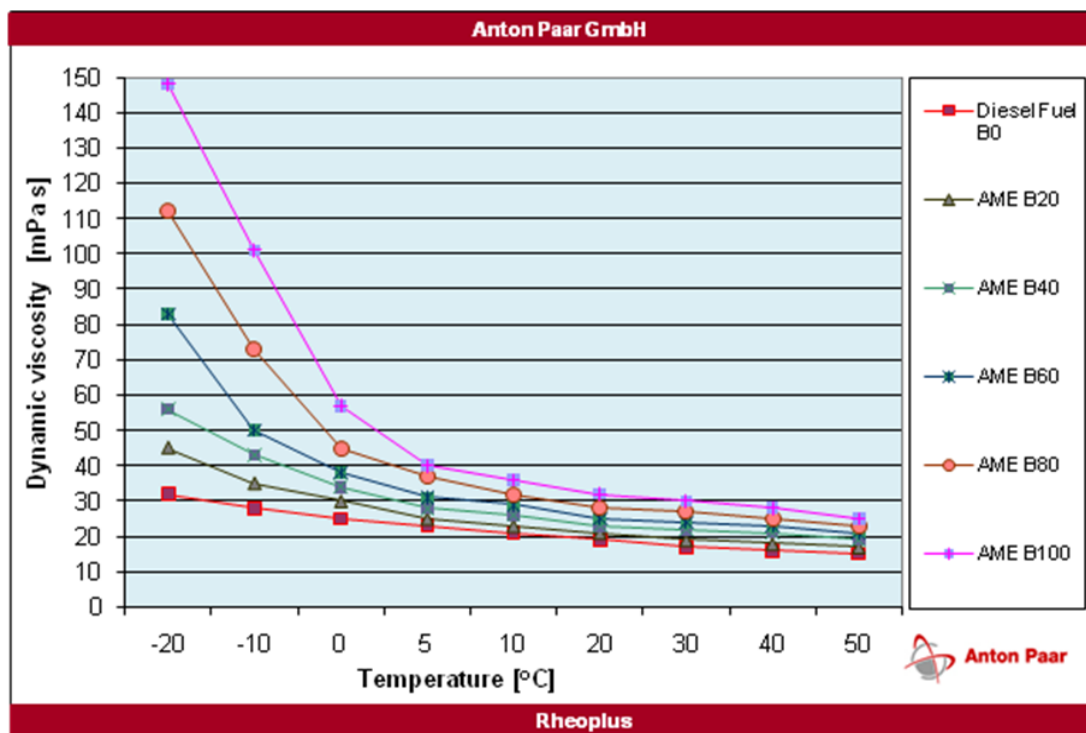


Fig. 5. Dynamic viscosity of biofuel containing AME produced from waste fat as a function of temperature

### CONCLUSIONS

- The tests have shown that the dynamic viscosity of the biofuel "B" is temperature dependent.
- Rheological properties of biofuels depend on the content of bio-components AME.
- Especially the dynamic viscosity grew rapidly after cooling biofuels to temperatures below 0°C.
- Dynamic viscosity of B100 AME Biodiesel produced from pure animal fat in the temperature range from 50 to -20°C has the value of c.a. 20 to 150[mPa·s]. Dynamic viscosity of Biodiesel B100 AME produced from animal fat was on average higher by about 5 to 10 [mPa·s] than that of AME manufactured from pure fat. Dynamic viscosity of B80 AME biofuels at 50°C was 21[mPa·s]. When the temperature was decreasing its value was increasing and at -20°C reached 100[mPa·s]. Dynamic viscosity of B60 biofuel at 50°C was 20[mPa·s], but with cooling fuel sample it was growing to reach 80[mPa·s] at -20°C. Dynamic viscosity B40 is in the range from c.a. 19 to 50 and B20 is in the range of c.a. 15 to 45 [mPa·s]. For comparison, the dynamic viscosity of Fuel Diesel in

the temperature range from 50 to -20°C has the value of c.a. 15 to 32 [mPa·s].

- Therefore, for a better assessment of the effect of Diesel 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 the engine feeding with biofuels and biocomponents.

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