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INFLUENCE OF PRESSURE ON DYNAMIC VISCOSITY OF OIL

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Abstract

The viscosity of lubricant is physical quantity, which has major impact on slide bearings and micro-bearings functioning parameters. Applying computer simulations as a tool to study the hydrodynamic lubrication phenomenon, researcher should create a computational model as close as possible to the real object, therefore the knowledge about a viscosity dependence on temperature and shear rate of bearing lubricating oil is essential in simulations of slide bearings hydrodynamic lubrication. This paper present research, which show, that also an influence of pressure on oil dynamic viscosity should be taken into consideration.

The aim of this work is to determine the influence of pressure on the dynamic viscosity of lubricating oil. In this research the selected new and used engine oils were investigated. The dynamic viscosity of oil was measured at different pressures and temperatures in the function of shear rate.

In this work the engine oils of passenger vehicles were investigated. The viscosity measurements for new and used lubricating oils were made with the Thermo Scientific Haake Mars III rheometer.

The received information will be used in the simulations of hydrodynamic lubrication of slide bearings and micro-bearings. Fitting viscosity curves, described by a viscosity model adopted in simulations, to the experimental data, obtained for motor oils, will allow to find the values of coefficients of that model. The determined coefficients will be set in the relationship defined by the adopted viscosity model, implemented in the used for simulations CFD software. Collected data may also be useful for designing bearings and sliding friction pairs.

Keywords: *dynamic viscosity, engine oil, pressure dependence, temperature dependence, shear rate*

1. Introduction

The viscosity is a key parameter determining the properties of lubricating oil. In order to obtain correct results in numerical simulations, which concern hydrodynamic lubrication of slide bearings, a accurate input data to the adopted model is required. The assumption, that the lubricating oil in investigated bearing has a constant value of viscosity over whole range of shear stress, temperature, pressure and other taken into account quantities, for example the magneto-rheological properties [4], can lead to a not quite accurate values of resulted hydrodynamic pressure distribution or lift and friction force of such bearing. The properties of the lubricant are also influenced by the time of its operation [5]. Some authors show the importance of taking into account other factors that affect the dynamic viscosity and also the hydrodynamic pressure distribution in slide bearings [7]. Therefore, it becomes necessary to find the relation describing the change of viscosity as a function of the considered physical quantity.

This work is focused on determining the changes in viscosity value, with accordance to the pressure changes. In previous papers [1-3] were presented the tests of viscosity dependence on shear rate (for relatively wide ranges of shear rates) and on temperature. In this research, the viscosity measurements were also performed on the Thermo Scientific Haake Mars III rheometer, however, with the measurement system called a *pressure chamber* shown in Fig. 1, which allows to determine the change in viscosity of the sample at varying pressure. The applied instrument allows one to study the properties of a sample for maximum allowed pressure 100 bars (higher pressures are permitted while maintaining additional conditions).

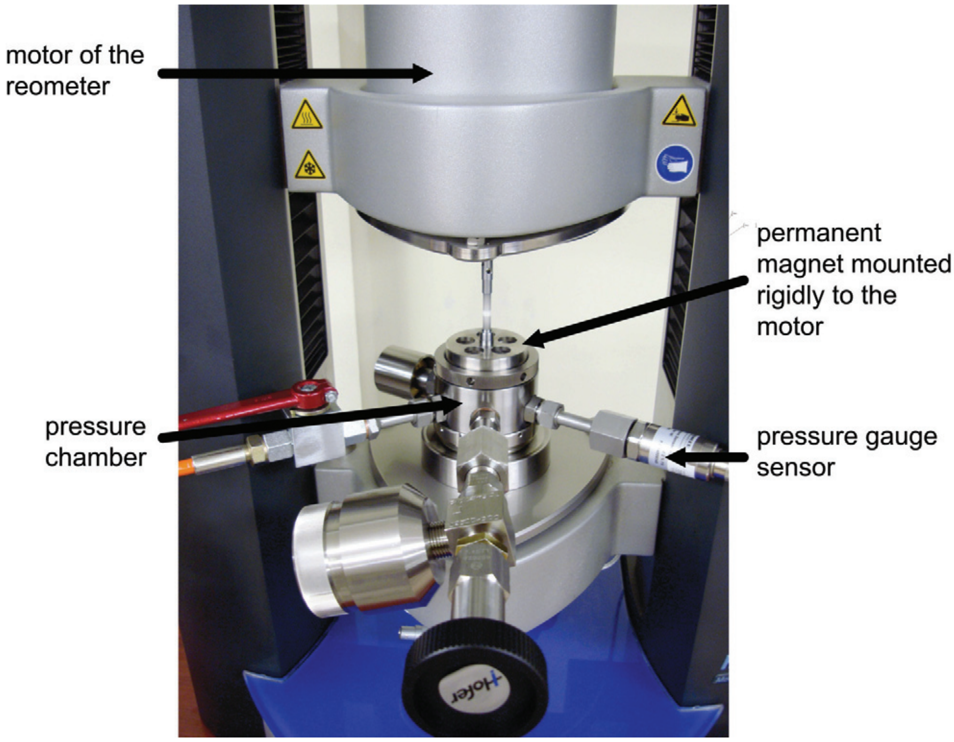

Fig. 1. The pressure chamber used with the Thermo Scientific Haake Mars III rheometer to measure the viscosities of different pressures and temperatures of investigated oil

In this investigation the PZ38 rotor, shown in Fig. 2, was used for measurements with pressure chamber. This rotor is mounted on two sapphire bearings and is magnetically coupled with the magnet rigidly attached to the motor of the rheometer. The pressure chamber is located in the water jacket used for temperature control. The temperature control system uses water as a medium. The Haake Mars III is at present a high end rheometer, despite this, the accuracy of the results obtained by using the described above measuring system, depends largely on the preparation of the device by the operator. First, the researcher must take into account the effect of temperature on the magnetic coupling of the rotor, therefore, after changing the temperature, this makes it necessary, to determine the optimal distance between the magnets. Then the operator performs tests to determine the effect of non-ideal alignment of the rotor and also the influence of friction forces, which occur in the rheometer bearings. The next step is to recognize the impact of the friction in the sapphire bearings of the rotor. These bearings are lubricated with the investigated oil. After such calibration performed, the user fills the pressure chamber with the oil. One measurement requires about 50 ml of the sample to fill the chamber and an additional amount to increase the pressure and the fulfillment of the supply system, i.e. hand pump.

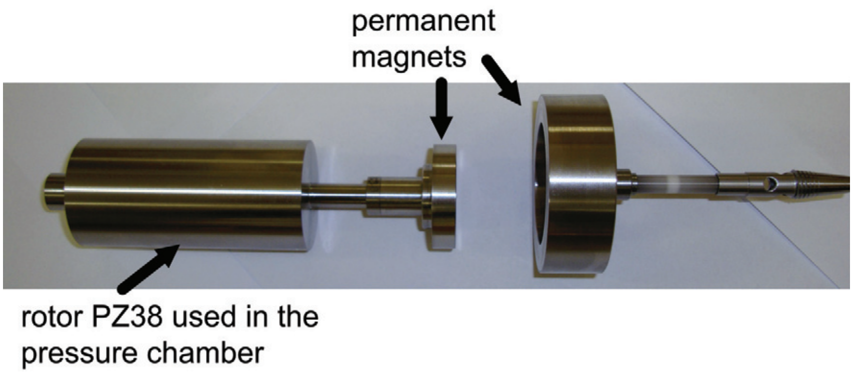

Fig. 2. The rotor PZ38 used for measurements in the pressure chamber

The investigation concerned the non-used Pennzoil LongLife Gold, which satisfy the SAE 15W-40 standard. This oil was used as a base oil of ferro-fluids, investigated in papers [2, 3].

2. Results

The dynamic viscosity measurements were performed in the CR mode (constant rotation). In this mode, the rotation speed is set to a constant value and torque is measured. The measurements were made in the range of shear rates from 15 to 200 [1/s] and gauge pressure to 100 bars. In Fig. 3 are shown the results at temperature $t = 30°C$.

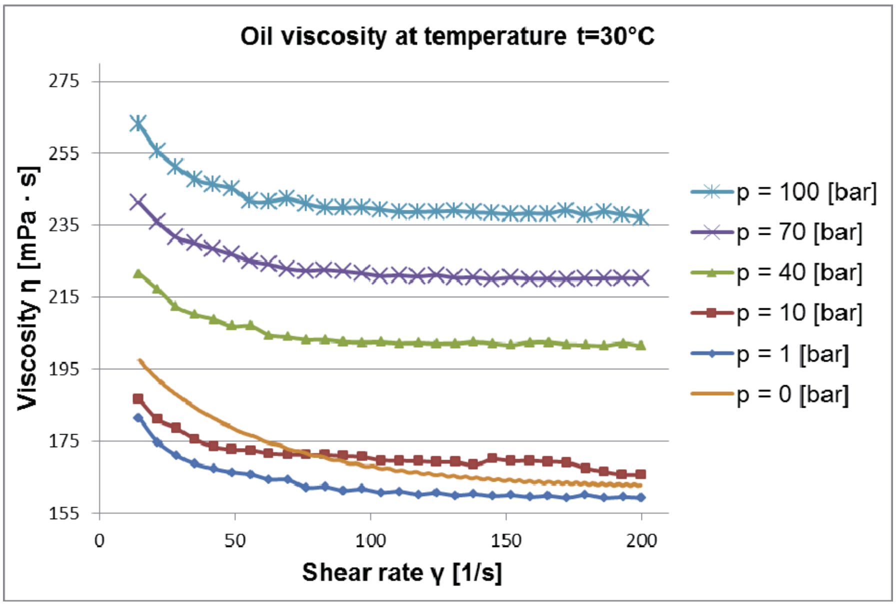

Fig. 3. The viscosity vs. shear rate dependency for investigated oil at different pressures and temperature t =30°C

The viscosity measurements with the pressure chamber were made at gauge pressures 1, 10, 40, 70 and 100 bars. Graphs show the results averaged for several measurements, each of which was made on a new sample, after the previously performed calibration process The measured viscosity at 0 bar (i.e. at ambient air pressure) was cited from paper [2] for comparison of obtained results. Those measurements were performed with the same rheometer, but with the cone-plate configuration and Peltier's temperature control system. It can be observed, that increase of the oil pressure increases its viscosity. Interesting is the fact, that flow curve at pressure 0 bars intersects with the curves at pressures 1 and 10 bars. It is due to the differences of used measuring systems. The measurement of viscosity with the pressure chamber demands much larger volume of the sample, about 50 ml, while with the cone-plate configuration just 1 ml, therefore establishing the temperature of a sample and receiving the heat generated in the process of viscous heating is much faster and more accurate in case of cone-plate configuration with Peltier's temperature control system, than in case of pressure chamber with water jacket and a thermostat that regulates the temperature of the water. It should be noted that the temperature is not directly measured in the sample, but that value is measured for the component located in direct contact with the sample. Moreover, all elements, which the oil is in contact, are made with the materials with good heat conductivity and a relatively large heat capacity, so even mass differences of both configurations have a significant impact on the accuracy of the results. The quality of the results was also influenced by occurring leaks, especially for higher pressures and temperatures. In such cases, there were attempts to compensate the pressure drop. If the pressure deviation during measurement were not greater than 3%, than these results were taken into consideration, so it resulted in the shape of the some viscosity curves.

Figure 4 shows results at the same manner as in Fig. 3, but for measurements at sample temperature $t = 60°C$.

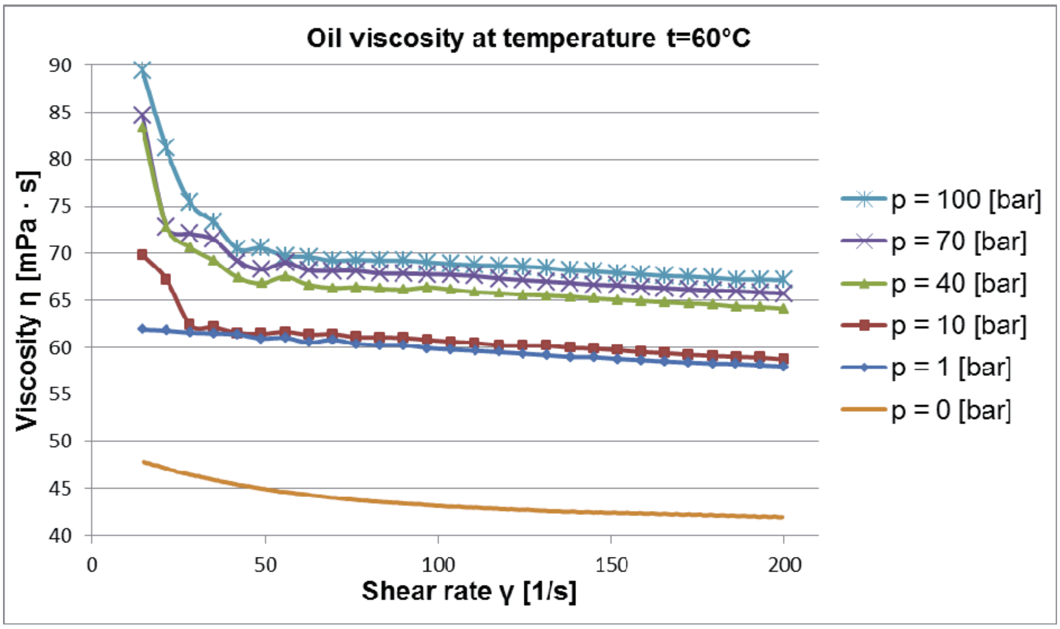

Fig. 4. The viscosity vs. shear rate dependency for investigated oil at different pressures and temperature t =60°C

In this case, the differences in the results obtained using a pressure chamber in relation to the cone plate, are relatively large. It is suspected that this is due to improper fitting of the gap between the magnets in the calibration process. For a given temperature, a calibration was performed, after which, was followed by series of measurements. The process of finding the optimum gap for each temperature was carried out only at once and perhaps, during this process, due to the thermal capacity of elements of the system, not all components have reached the desired temperature, therefore the results should be verified in future studies. Further, the accuracy of the results may be affected by other aspects of the calibration process, which also depends on temperature. However, it should be noted a significant influence of pressure on the dynamic viscosity of oil also at this temperature.

In Fig. 5 are presented flow curves for different pressures at temperature $t = 90°C$.

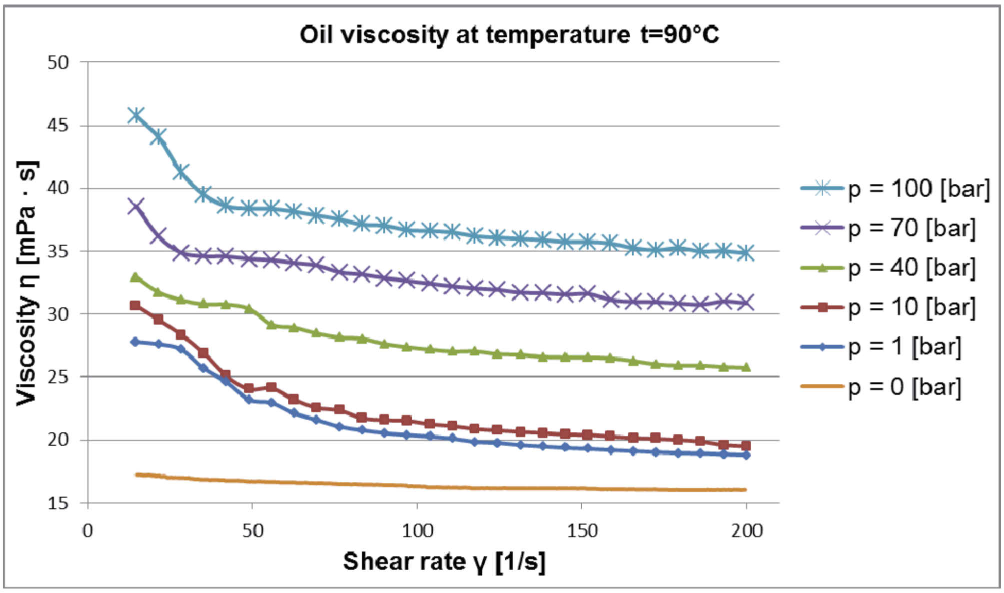

Fig. 5. The viscosity vs. shear rate dependency for investigated oil at different pressures and temperature t =90°C

It can be observed a different behavior of viscosity curve, according to the results obtained at a pressure 0 bars in the configuration cone-plate, i.e. the significant differences between small and large shear rates appear. This is probably affected by the viscous heating of oil. Each test started at low shear rates and after the measurement at each step the shear rate was increased to the next value. An increase of the duration of each step will allow to establish stable conditions and to obtain accurate values. Nevertheless, there was indicated, that also at this temperature, close to the base operating temperature of such oil (i.e. engine temperature), the effects of pressure on the dynamic viscosity is significant.

3. Discussion

The results show that the value of the oil pressure may have a significant effect on its viscosity. For example, in Fig. 6 is shown the change in the value of oil viscosity depending on the pressure, at a shear rate of 100 1/s at temperatures 30°C, 60°C and 90°C. In the book [6], the author reports that viscosity dependence on pressure of mineral oils can be described by the Barus relationship:

$$\eta = \eta_0 \cdot \exp(\alpha \cdot p)\,, \tag{1}$$

where η_0 and α are material constants of the lubricant. Fig. 6 shows also the fitted curves and the evaluated material coefficients η_0 [mPa·s] and α [-] with specified coefficient of determination R^2.

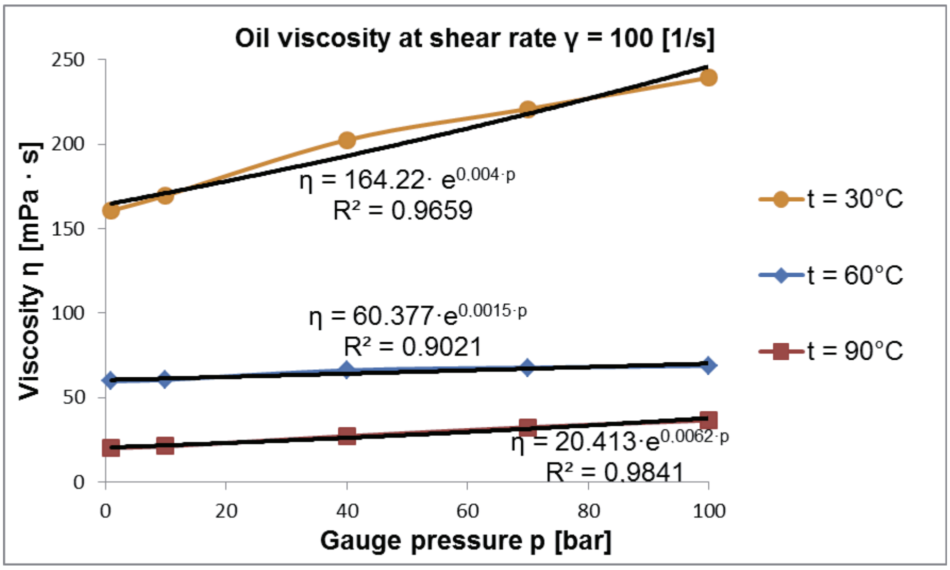

Fig. 6. The viscosity vs. pressure at shear rate 100 1/s and at temperatures 30°C, 60°C and 90°C with fitted curves described by the Barus relationship

It should be considered, that it was noticed in [6], that the Barus relationship used for higher pressures than 5 bars may be inappropriate model and can cause large errors.

Further studies are planned to be performed in a wider range of shear rates. It is also planned to investigate the influence of pressure changes on the viscosity of the ferro-oils, however, the problem of the impact of the magnetic field generated by the rotor magnets on the sample properties, may occur. Furthermore, this studies have required the use of large amounts of tested oils, which are usually mostly fail to recover after measurements. Moreover, this portion of the oil, that has been recovered, was full of air bubbles. This was due to a sharp decrease of oil pressure after the test (decreasing the pressure of the sample to ambient pressure by opening the drain valve). This obviously affects the properties of such oil and it cannot be re-used in the measurement, at least temporarily. Therefore, the investigation of ferro-oils properties in pressure chamber, can be difficult to obtain due to economic reasons.

The results will be used in the studies of hydrodynamic lubrication of slide bearings.

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