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STUDIES ON DYNAMIC VISCOSITY CHANGES OF THE ENGINE'S LUBRICATION OIL DEPENDING ON THE PRESSURE

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Abstract

This paper is a part of the wider author's research on the development of the new mathematical model for description of the viscosity changes of the lubrication oil in the exploitation time. Pressure of the oil is a variable parameter in the combustion engine and depends on many design parameters such as oil pump efficiency, geometry of the channels and lubricated element. It depends also on the exploitation parameters, such as rotational speed of the engine or contamination degree of the oil filter. So big amount of the factors, which have an influence on the pressure, resulted in the decision to examine, how big influence has a pressure in the oil viscosity. For the researches, the oil samples from the different combustion engines, both petrol and diesel, with different capacities, were taken into account. In each case, for the examination were taken samples both for the fresh oil and used oil from the change. Results of this research are shown in the tabular in correlation to the engines specification. In the next researches, after collecting all the oil ageing data, author will examine the pressure distribution in the slide bearing. After that it will be will possible to estimate the importance of the pressure changes for the proper work of the engine.

Keywords: *oil ageing, viscosity characteristics, ageing model, rheology*

1. Introduction

The viscosity of the lubricating oil is an essential parameter which provides the possibility of its use in internal combustion engines. This value is influenced by many parameters. Natural factors are primarily temperature [2] and shear rate [1]. Apart from these two parameters, during its exploitation, oil loses its properties due to ageing and pollution, what has a direct impact on the value of the viscosity. The author in earlier studies [3, 4], examined the effects of temperature, shear rate and oil pollution on the dynamic viscosity changes. This research aims to create a new mathematical model which will describe the process of viscosity changes and oil ageing in internal combustion engines. For a complete view on the viscosity changes, the oil viscosity changes of the lubricating oil by the changes of pressure are missing. Oil pressure is one of the most variable parameters in internal combustion engines. Its value depends on the load of the friction node, rotational speed, dynamic viscosity, oil pump parameters, shape of the lubricated parts and degree of contamination of the oil filter.

The overall effect of pressure changes on the changes in viscosity of the oil is already well known in fluid mechanics [5] and is described by Barus equation (1):

$$\eta_p = \eta_0 \cdot e^{\alpha\, p}, \tag{1}$$

where:
η_p – lubricant viscosity at pressure p and temperature T [Pas],
η_0 – lubricant viscosity at atmospheric pressure and temperature [Pas],
α – pressure – viscosity coefficient [m^2/N].

Experimental studies on the impact of pressure on the viscosity of the oil and the comparison of the characteristics of the new and exploited oil, will help to find the parameters, which have an influence on the viscosity model of the motor oil. A better understanding of these differences will help to move to the next stage of research, which is the numerical modelling of hydrodynamic lubrication of the slide bearings with taking oil aging into account.

The purpose of this study is to examine the impact of the oil pressure on the viscosity of the examined samples and to describe the changes in the characteristics of the new and exploited oil. To achieve this aim, the Haake Mars III rheometer, equipped with a pressure chamber, has been used. Available measuring equipment can test the pressure influence into viscosity in pressures up to 100 bar. To ensure continuity of research and for comparison purposes, the study was carried out for a constant shear rate of 150 1/s and temperature of 90°C. Selection of the shear rate is assumed because of the earlier studies on viscosity, which were performed on the plate-cone set, wherein the maximum shear rate is 200 1/s. The temperature was set to 90°C due to the fact that this is the normal operating temperature of the engine in passenger cars.

2. Experimental research

The tested samples come from the passenger cars, equipped with the both, diesel and petrol engine. For each engine, two samples of the motor oil were tested. The first sample is a sample of the new oil, poured into the engine by the oil change, and the second sample is taken from a later change the oil in the engine, made in accordance with the plan of maintenance for the engine. The following oil samples have been tested:

- Shell Helix AV-L, with the viscosity grade 5W30, exploited in the passenger car Volkswagen Touran, equipped with the turbocharged diesel engine, with the capacity of 2.0 L. The first sample, marked as 1a, is for the new oil, and the second one, marked as 1b, was taken out from the engine by the mileage of 27 000 km.
- Castrol Magnatec Professional A3, with the viscosity grade 10W40, exploited in the passenger car Toyota Yaris, equipped with the petrol engine, with the capacity of 1.0 L. The first oil sample, described as 2a, is for the new oil, and the second one, described as 2b, was taken out from the engine by the mileage of 15 000 km, according to the maintenance plan.

In order to preserve the continuation of the researches and in the follow of primarily assumed parameters, was decided, that the research will be performer under the following conditions:

- shear rate: constant value 150 1/s,
- temperature : 90°C,
- pressure: regulated in the range between 0 and 80 bar, with the measurements after every 5 bar.

For each of the oil samples, the research on the viscosity changes with the increase of pressure, have been performer on the Haake Mars III rheometer, equipped with the high pressures chamber, according to the following plan:

- calibration of the measure system has been performed,
- high pressure chamber has been filled with the oil and the chamber has been ventilated,
- for the pressure of 0 bar, the first measurement series of viscosity have been performed; each of the series contain 100 viscosity measurements and takes 30 seconds; for the further calculations, the average value has been taken under consideration.
- next series of the measurement have been performed after increasing of the pressure in next 5 bar.

3. Results of research

During measurements, was noticed, that for each sample, the viscosity increases as the pressure increases, what corresponds the references [5]. For the pressures of 10 bar and higher, stabilization of the measurement results was noticed. Results of the research have been presented in Tab.1.

Because the fact, that the value of viscosity stabilizes after exceeding of the value of 10 bar, was decided, to check the value of the deviations from the average value in the range between 10 and 80 bar. Deviations of the viscosity from the average value, after exceeding pressure of 10 bar, are:

Tab. 1. Oil viscosity in dependence on pressure

Pressure [bar]	Viscosity [mPas]			
	Sample No. 1a	Sample No. 1b	Sample No. 2a	Sample No. 2b
0	11.30	8.10	24.82	18.91
5	16.87	12.88	34.11	26.72
10	24.87	19.10	35.24	30.81
15	25.36	19.28	35.27	30.96
20	25.58	19.36	35.40	31.25
25	25.67	19.15	35.27	31.26
30	25.68	19.25	35.17	31.24
35	25.63	18.86	35.03	31.21
40	25.52	18.89	34.67	31.29
45	25.57	18.51	34.99	31.32
50	25.38	18.38	34.88	31.28
55	25.49	18.34	34.80	31.22
60	25.61	18.33	34.47	31.24
65	25.64	18.23	34.30	31.07
70	25.66	18.23	34.40	31.26
75	25.60	18.26	34.46	31.29
80	25.75	18.29	34.47	31.25

– 2.6% for the sample 1a and the average viscosity value 25.53 [Pas],
– 3.6% for the sample 1b and the average viscosity value 18.70 [Pas],
– 1.6% for the sample 2a and the average viscosity value 34.86 [Pas],
– 1.2% for the sample 2b and the average viscosity value 31.20 [Pas].

Because of the fact, that every point of the characteristic is an average value of 100 measurements, the highest value of the deviation at the level of 3.6 % has been accepted. It is an allowed measurement error, which is a result of the accuracy of the measurement devices and eventually influenced by the calibration.

Author of the study attempted to fit the real measured characteristics into the characteristics resulting from the Barus equation (1), however, neither in statistical nor in analysis way it wasn't possible. Therefore, for the real characteristics, the theoretical characteristics in the form of an exponential equation, which art most similar to the equation Barus, have been fitted. Their values are presented in Tab. 2.

Tab. 2 Obtained viscosity η(p) characteristics

Researched oil sample	Characteristic
1a. Diesel new	$\eta_p = 25.75 - 15.01 \cdot e^{-0.17 \cdot p}$
1b. Diesel used	$\eta_p = 18.74 - 10.18 \cdot e^{-0.20 \cdot p}$
2a. Petrol new	$\eta_p = 34.85 - 10.03 \cdot e^{-0.54 \cdot p}$
2b. Petrol used	$\eta_p = 31.29 - 12.47 \cdot e^{-0.23 \cdot p}$

Real and obtained characteristics are presented in graphical form on the Fig. 1 for the samples 1a and 1b and on the Fig. 2, for the samples 2a and 2b.

From the analysis of the values of viscosity, presented in Tab. 1. and from their comparison with the equations presented in Tab. 2, occurred, that the first part of the equation is a high pressure value, in which the pressure stabilizes. Resulting from this statement, author of this research suggests

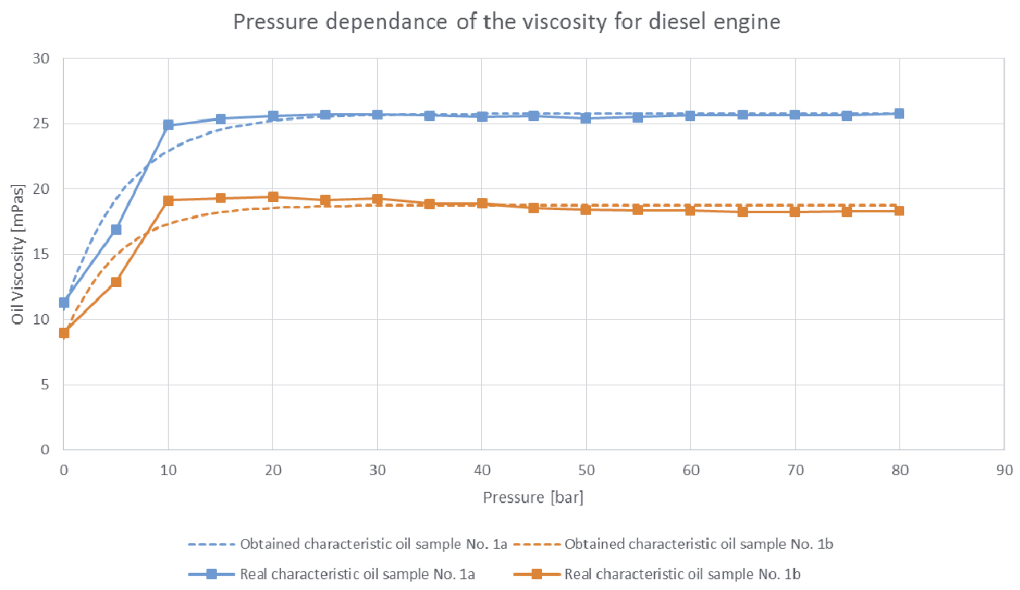

Fig. 1. Real and obtained characteristics for the oil exploited in diesel engine

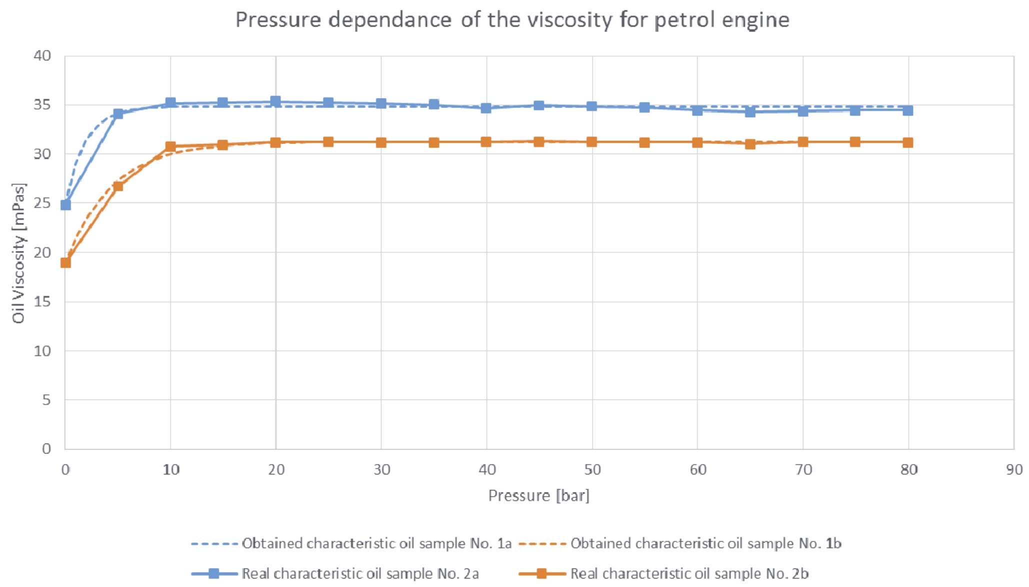

Fig. 2. Real and obtained characteristics for the oil exploited in petrol engine

to present the viscosity changes by the increasing of the pressure in accordance to the following equation (2):

$$\eta_p = \eta_{hp} - \beta \cdot e^{\alpha \cdot p}, \tag{2}$$

where:

η_p – lubricant viscosity at pressure p and temperature T [Pas],

η_{hp} – lubricant viscosity at high pressure *p* and temperature *T*, after viscosity stabilization [Pas],

β – Viscosity coefficient [Pas],

α – Pressure coefficient [m^2/N].

Further analysis was research on the change in viscosity with oil aging. In order to determine the effect of aging on the characteristics shape of the oil viscosity changes with increasing pressure, the differences between the values of the viscosities of the new and used oil in the correspondent pressures, have been compared. For pressures greater than 15 bar, the average viscosity was assumed. Results of comparison are presented in Tab. 3.

Tab. 3. Ageing influence on characteristics

Pressure [bar]	Viscosity difference [mPas]	
	Diesel engine, Sample No. 1a and 1b	Petrol engine, Sample No. 2a and 2b
0	2.30	5.91
5	4.00	7.39
10	5.77	4.43
15-80	6.91	3.60

In case that the viscosity values for new and used oil were different in a fixed amount, adjusted for measurement error, through the whole characteristic, it could be stated that aging does not affect the change in viscosity with pressure. Meanwhile, the reported differences between the values of viscosity for new and used oil increase or decrease depending on the oil sample in a significant value. These studies demonstrated that aging has an impact on the viscosity by increasing of the oil pressure.

4. Conclusions

Through the conducted research and made analysis, the aims of this study have been achieved. Both the characteristics of pressure dependence on oil viscosity has been designated and the influence of ageing on the characteristics have been proved. Results of this research will be used for the further creation of the mathematical model, which will describe viscosity changes resulted by the oil ageing. Every conclusion stated in this study will be taken into account by the next researches and analysis.

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