

Evaluation of deterioration of engine oil properties in the function of mileage

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Abstract. The paper involve testing of various engine oils – synthetic and semi – synthetic – in terms of viscosity change at different temperatures and the degree of wear. New and used oils were compared. This is an important issue for determining the reliability of motor vehicles, anticipated repairs and maintenance. As a result of the process of exploitation, engine oils are subjected to physicochemical changes. The impact on the deterioration in the condition of the lubricating liquid have, among others high pressure, temperature, pollution or oil oxidation. Therefore, it is necessary to change the engine oil after the mileage recommended by the producer . However, these recommendations may not be adequate for the actual consumption of liquids, which is determined by the technical condition of the engine and the course of the operation process. Determining the optimal replacement time is an important issue due to the reduction of operating costs and reduction of emissions of environmentally harmful exhaust. For this purpose, the viscosity depending on the temperature of different oils with various degrees of wear, tear, and obsolescence were measured. Characteristic points were determined and a mathematical model describing these changes was created. It was noticed that the greatest changes in viscosity occur at a temperature of 0 °C to 40 °C, whereas from 40 °C the viscosity changes appear in a smaller range for all oils and the viscosity was below 100 mPa.s. Results of comparing the new and used oil was evaluation of the change of their lubricating properties. The aim of this paper was to conduct viscosity tests of selected engine oils using a rotational viscometer in order to check the degree of engine oil consumption due to the degree of exploitation.

1. Introduction

Already in ancient Egypt, chariot wheel axes were lubricated with animal fat. This kind of oils and vegetable oils were used until the middle of the 19th century. Then mineral oils were used, obtained from the refining of crude oil, whose properties were enriched with enriching additives. Nowadays, multi – grade synthetic oils are most often used [1], [11].

The evolution of automotive engine construction solutions is related to the need to constantly improve the parameters of lubricating oils. This is an important issue for determining the reliability of motor vehicles, anticipated repairs and maintenance. As a result of the process of exploitation, engine oils are subjected to physicochemical changes. The impact on the deterioration in the condition of the lubricating liquid have, among others high pressure, temperature, pollution or oil oxidation [2]. Therefore, it is necessary to change the engine oil after the mileage recommended by the producer . However, these recommendations may not be adequate for the actual consumption of liquids, which is determined by the technical condition of the engine and the course of the operation process.



Determining the optimal replacement time is an important issue due to the reduction of operating costs and reduction of emissions of environmentally harmful exhaust. For this purpose, the viscosity depending on the temperature of different oils with various degrees of wear, tear, and obsolescence were measured [3].

The aim of this paper was to conduct viscosity tests of selected engine oils using a rotational viscometer in order to check the degree of engine oil consumption due to the degree of exploitation. The most desirable tests of viscosity changes of motor oils are studies that reflect the realities of their work in car engines. They allow to observe changes in viscosity of these liquids during the cold engine start – up and during its intensive operation, when the oil operates at over 100 ° C. The paper involves testing of various engine oils – synthetic and semi – synthetic – in terms of viscosity change at different temperatures and the degree of wear. New and used oils were compared. Results were presented by the viscosity – temperature characteristics, which allows to observe changes in the viscosity value under the influence of exploitation.

2. Methods

In order to determine the qualitative changes of the used oils, they were compared with new oil. The test was carried out using a Brookfield rotary viscometer model DV2T (Figure 1). The device performs the measurement with an accuracy of $\pm 1\%$ of the full measurement scale for the selected pair of parameters: type of spindle and measuring speed [4]. A thermocouple attached to the viscometer was used to measure the temperature, and the temperature stabilization of the tested oils was obtained using the LWT 2/150 water bath. Samples of used engine oils were collected in reference to the three new oils with similar properties. Dynamic viscosity was assumed as the comparison parameter.

To compare used oils to new ones, the values of dynamic viscosity of all tested oils – either new and used – were set in the temperature range from 5 ° C to 80 ° C with the registration of many measuring points with averaging. The time interval lasted 20 seconds and averaging – 10 seconds. Measurement of one sample was divided into stages due to the limited measuring range, which depends on the fixed speed of the measuring spindle and its size. The measuring range determines the range of viscosity which changes with increasing temperature. For this reason, it was necessary to use a smaller sized spindle to measure high – viscosity substances and indicate the proper speed [4].

It is important that the spindle used and the rotational speed do not exceed 40 – 100% of the deflection of the measuring spring (% scale). If the range is exceeded, the measurement should be stopped and the spindle or rotational speed changed. If the value was below 40% of the scale, it was necessary to increase the speed or to change the spindle to a larger one. However, if the viscometer has reached the maximum speed (200 rpm) while using the smaller spindle, it was required to replace the spindle with a larger one, having a measuring range for lower viscosity values [4].

The measuring samples were in a low 600 ml Griffin beaker. To the beakers, according to the recommendations of the manufacturer of the test apparatus, at least 550 ml of the tested liquid was poured. Figure 2 shows the view of measuring the lubricating liquid in a Griffin beaker together with the submerged spindle LV-01 (61) and thermocouple [4].



Figure 1. Stand for dynamic viscosity measurement [source: own study]

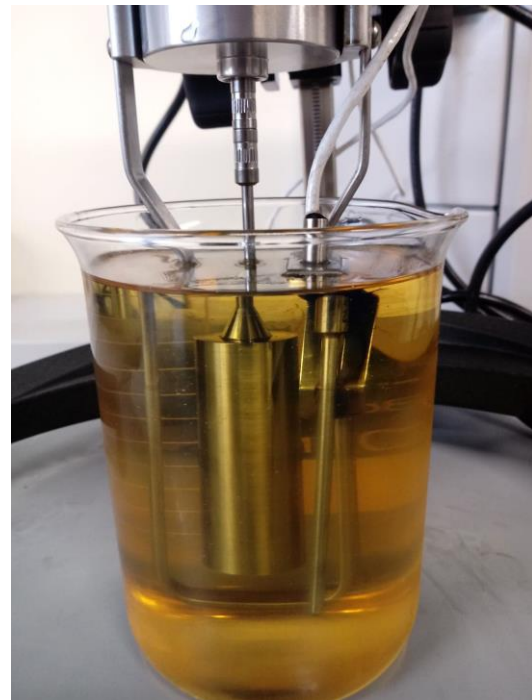


Figure 2. A view for spreading during the study [source: own study]

Investigation were divided in a few steps. Firstly the samples were refrigerated to obtain the temperature 5°C of the examined oils. Next the measuring of the viscosity was performed until the room temperature 20°C . Then Griffin beaker were placed in the water bath where the temperature had been increased to 80°C and in the meanwhile the measurements had been continued. Finally, the viscosity value in 100°C was calculated through extrapolation and the parameters such R^2 and equation were obtained.

3. Materials

Investigations were carried out to answer the question when the oil change is really due and compare it to the course recommended by the lubricant fluid manufacturer. The research materials were synthetic and semi – synthetic commercial engine oils produced by various manufacturers with different viscosity grades.

New and used engine oils were examined. Samples of used engine oils were collected in reference to the three new oils with similar properties. Table 1 presents a list of selected physico – chemical properties of the tested new oils in accordance with the specifications of these products [5-7]. Three samples of new engine oil were obtained in warehouses, and five samples of used – during the technical replacement of lubricating oil for engines of various passenger cars. Two of these used oil samples were exchanged after approx. 10-15 thousand. km, which is the period recommended by the most manufacturers. The rest three samples of used oil were exchanged after the mileage of 15.5, 17 and 25 thousand km. Users of randomly selected cars, from which oils have been taken, had a different culture of use [8], [10], [14].

Table 1. Selected information about new samples of engine oils [5-7].

<i>Sample</i>	<i>SAE Viscosity Grades</i>	<i>Type</i>	<i>Pour point</i>	<i>Flash point</i>	<i>Kinematic viscosity at 40°C (mm²/s)</i>	<i>Kinematic viscosity at 100°C (mm²/s)</i>
01	5W-40	synthetic	-	220	89	14.3-15.3
02	5W-30	synthetic	-36	230	68	11.0
03	10W-40	semi-synthetic	-42	215	90	13.5-14.5

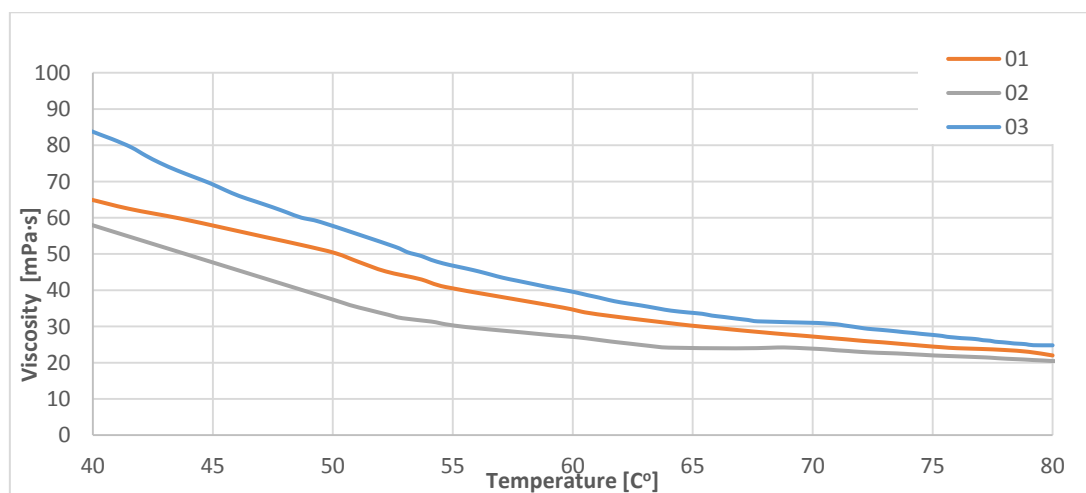
Table 2. Selected information about used samples of engine oils [5-7].

<i>Sample</i>	<i>SAE Viscosity Grades</i>	<i>Mileage of oil in the exchange period [km]</i>
01.1	5W-40	25 000
02.1	5W-30	15 000
02.2	5W-30	15 500
03.1	10W-40	12 000
03.2	10W-40	17 000

4. Results

The most desirable tests of viscosity changes of motor oils are tests that reflect the real conditions of their work in car engines. It allows to observe changes in viscosity of these liquids during the cold engine start-up and during its intense work, when the oil operates at over 100° C [9]. The following Infographics show the viscosity – temperature characteristics. By analyzing them, it can be observe that the viscosity of oils varies according to the mathematical exponential distribution. This is due to typical additives used in engine oils such us antiwear, viscosity modifiers, dispersants, friction modifiers, defoamers, deemulsifiers, adhesion agents.

The viscosity – temperature characteristics listed below show changes in the dynamic viscosity value for new (Figure 3) and for used oils (Figure 4) depending on the temperature increase. In both cases, the characteristics are exponential. Thanks to this knowledge, algebraic equations describing these variations can be used to predict the value of dynamic viscosity at any temperature.

**Figure 3.** The viscosity – temperature characteristics of new oils

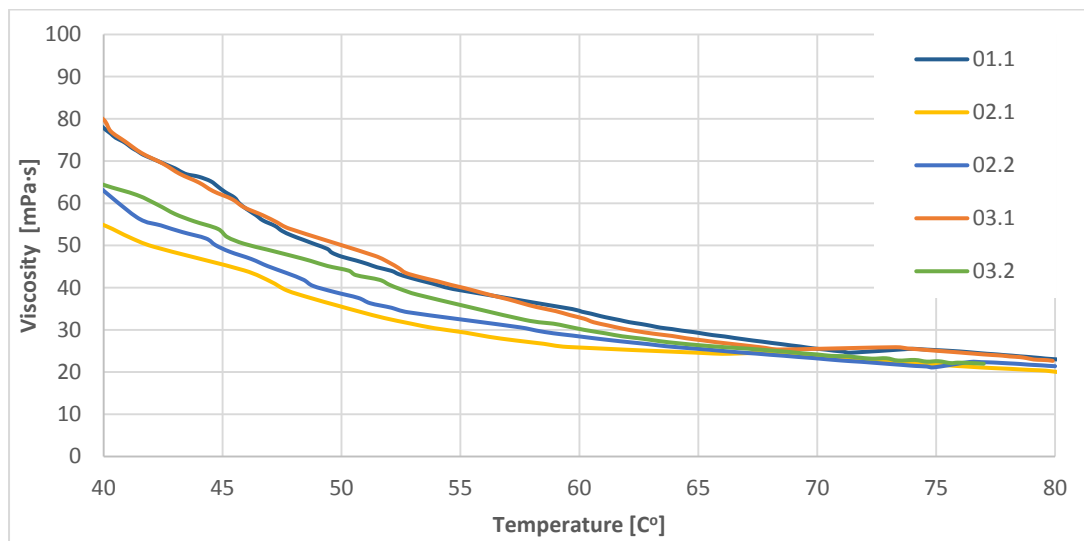


Figure 4. The viscosity – temperature characteristics of used oils

The typical temperature of the engine oil is around 90 – 130 ° C. In order to extend the measuring range of oils in the engine an extrapolation of 100 ° C was carried out. Figures below shows comparison between new (sample 03) in reference to the new oils with similar properties (sample 03.2). Extrapolated values are marked by dotted line and the R – square value and equation are indicated on the chart (Figure 5). Similar figures were generated for all examined used oils and their corresponding new samples. Accuracies for other samples assume values close to the determined errors.

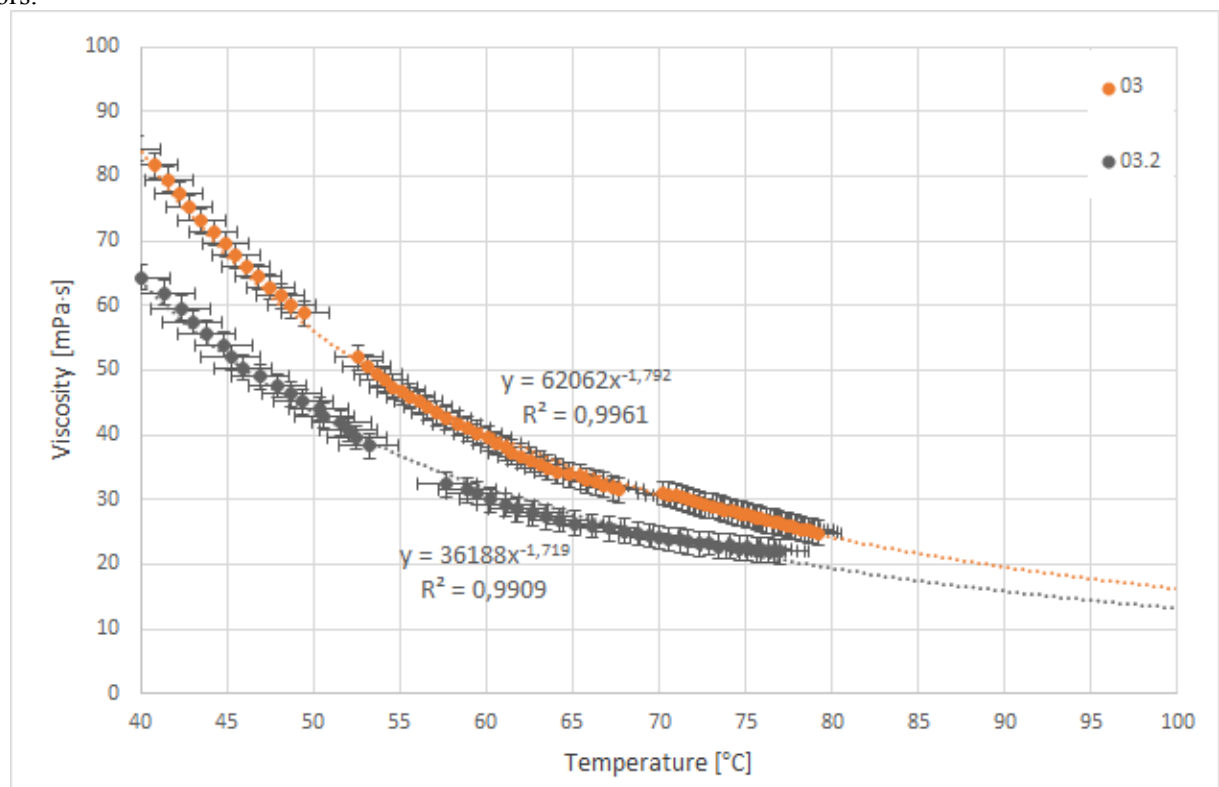


Figure 5. Extrapolated values of samples 03 and 03.2

The R^2 (the coefficient of determination) parameter that specifies the approximation's quality. This is a measure of how much the trend line is matched to the points of the chart. The R-square can vary between 0 and 1. Values closer to 1 indicate that the trend line represents the data series well. In the Table 3 there is summary of all analyzed samples. Regarding to data below it could be observed that extrapolated viscosity values in 100°C are reliable as the coefficient of determination R^2 is close to 1 in all cases (Table 3).

Table 3. Extrapolated viscosity values in 100°C

<i>Sample</i>	<i>Mileage [km]</i>	R^2	<i>Viscosity for 100 °C [mPa·s]</i>
01.1	25 000	0,982	14,68
01	new oil	0,994	15,04
02.1	15 000	0,965	14,67
02	new oil	0,964	15,60
02.2	15 500	0,989	13,08
02	new oil	0,964	15,24
03.1	12 000	0,970	14,21
03	new oil	0,996	16,23
03.2	17 000	0,991	13,20
03	new oil	0,996	16,17

In order to evaluate the usefulness of the used oils, the relative change in dynamic viscosity in relation to fresh counterparts was determined. The limit value that verifies the suitability of the oil for further use is defined as the change in dynamic viscosity by $\pm 25\%$ at a temperature above 40°C [12], [13]. Table 4 below shows the viscosity values of new oils for temperatures 40°C, 60°C, 80°C, 100°C. The second one (Table 5) presents the values of viscosity for used counterparts. In addition, Table 5 contains the relative change values [%] calculated on the basis of data in Tables 3 and 4. Taking into account such criterion for the assessment of reasonable replacement of engine oil, there were no oils which the relative change in dynamic viscosity was greater than 25%.

Table 4. Viscosity values of new oils for temperatures 40°C, 60°C, 80°C, 100°C

	Viscosity	Temperature (°C)
	μ (mPa·s)	
01	69,23	40
	33,90	60
	21,82	80
	15,04	100
02	46,74	40
	27,00	60
	20,40	80
	15,24	100
03	83,71	40
	39,44	60
	24,13	80
	16,23	100

Table 5. Viscosity values and values of the relative change of used oils for temperatures 40°C, 60°C, 80°C, 100°C

	Viscosity		Temperature (°C)
	μ (mPa·s)	Relative increase (%)	
01.1	73,01	5,46%	40
	34,31	1,21%	60
	22,95	5,19%	80
	14,68	2,44%	100
02.1	48,85	2,12%	40
	25,95	3,89%	60
	20,01	1,91%	80
	14,67	5,97%	100
02.2	57,61	23,24%	40
	28,09	4,04%	60
	21,39	4,85%	80
	13,08	14,19%	100
03.1	72,88	12,93%	40
	32,65	17,22%	60
	22,65	6,12%	80
	14,21	12,45%	100
03.2	63,77	23,67%	40
	30,00	23,94%	60
	19,37	19,71%	80
	13,20	18,39%	100

5. Conclusion

Measurements carried out in laboratory conditions allowed to consider the legitimate time of changing the engine oil after the recommended course by the lubricant fluid manufacturer. Results were analyzed on the basis of viscosity values as that parameter affects the work of combustion engines, their durability, reliability and economics. However, it must be highlighted that viscosity does not provide full information about the changes in qualitative engine oil in the aging process.

It can be noticed that new oils do not have to be changed as often as the manufacturer recommends. Thanks to comparison of used and new oils, it was shown that viscosity of new oils is always higher than viscosity of used oils. However, at high temperature condition (80°C) the viscosity values of both – used and new – oils are in the range of 19 – 25 mPa·s. Values of relative change in dynamic viscosity were not more than 25%. This allows to conclude that none of the samples tested had to be replaced. Regardless of the manufacturer's recommendations, after traveling a certain distance the oil still has good properties and there is no need to change it.

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