THE ESTIMATION OF LUBRICITY AND VISCOSITY OF ENGINE OILS

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Summary

The diagnostic and operating criteria as well as the environmental protection impose very diversified requirements on the parameters of work of car engine oils in the area of lubricity and rheological properties. The aim of the work was the estimation of resistance to wear of the elements lubricated with these oils working at sliding friction as well as the estimation of rheological parameters of the oils in the reference temperature and in sub-zero and low temperatures at controlled shear stress. The tested materials included mineral engine oils, semisynthetic and synthetic ones that belong to different viscosity classes. Wear defects were determined with the use of the four-ball testing machine and also the characteristics of viscosity were described with the help of the rotational rheometer. On the basis of the results of the tests, in accordance with the elaborated method it is possible to compare oils designed for application and, at the same time, diagnose the way in which they will secure motive nods in the conditions of operation.

Keywords: engine oils, lubricity, wear, viscosity, diagnostic, operation.

OCENA SMARNOŚCI I LEPKOŚCI OLEJÓW SILNIKOWYCH

Streszczenie

Kryteria diagnostyczne, eksploatacyjne oraz ochrona środowiska narzucają na parametry pracy samochodowych olejów silnikowych bardzo zróżnicowane wymagania w obszarze smarności i właściwości reologicznych. Celem pracy była ocena odporności na zużycie elementów smarowanych olejami, pracujących w tarciu ślizgowym oraz ocena parametrów reologicznych tych olejów, w temperaturze referencyjnej i w temperaturach ujemnych oraz niskich przy kontrolowanym naprężeniu ścinającym. Materiałem badań były handlowe oleje mineralne, półsyntetyczne i syntetyczne – wielosezonowe, przynależne do różnych klas jakościowych i lepkościowych. Wyznaczono dla nich skazy zużyciowe z wykorzystaniem aparatu czterokulowego oraz charakterystyki lepkości z wykorzystaniem reometru rotacyjnego. Na podstawie wyników badań, według opracowanej metody można porównać oleje przeznaczone do aplikacji i można równocześnie diagnozować jak będą one zabezpieczały węzły ruchowe w warunkach eksploatacji.

Słowa kluczowe: oleje silnikowe, smarność, zużycie, lepkość, diagnostyka, eksploatacja.

1. INTRODUCTION

Car engine oil is a primary link in functioning and preserving durability of the following unit: piston – ring – cylinder [13]. Apart from the basic function of lubrication, reduction of resistance to motion, decrease of energy loss caused by friction, maintenance of wear products and their oxidation in the dispersed state as well as counteraction of emergency wear, engine oils preserve leakproofness and cleanness of the unit, cooling and vibration damping [1,7,8,16,17]. They work in wide range of temperatures, especially when vehicles are exploited in winter and summer conditions. These actions must be fulfilled both in conditions of cold starting in winter and at heavily loaded and heated up engine during the hot summer. With regard to the operating parameters, engine oils belong to the definite SAE viscosity index [3] and API viscosity index and modification of packets of additives and the base is so designed that they are multi-seasonal, most frequently adapted for engines with spark ignition,

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self-ignition or they are all-purpose [4, 11]. The diagnostic, operating criteria and the assurance of energy-efficiency and environmental protection impose very diversified requirements on this group of oils [5, 6, 10, 12]. The results of the engine examinations as well as the tribological and road tests carried out on the testing cars decide on the designation of oil with a specific quality grade in accordance with the American Petroleum Institute (API). At each stage of the test the results are analyzed and the quality class is designated. The affiliation to the definite viscosity index by Society of Automotive Engineers (SAE) in winter and summer conditions depends on the parameters of structural, dynamic and kinematic viscosity which are obligatory for the producer in the case of signing the engine oil with a classification designation.

The aim of the work was the estimation of resistance to wear of the elements lubricated with these oils working at sliding friction as well as the estimation of rheological parameters of the oils in the reference temperature and in sub-zero and low temperatures at controlled shear stress.

2. MATERIAL AND METHODS

The testing material comprised of selected commercial mineral engine oils, semisynthetic and fully synthetic ones, which were divided into three groups. The first group contained mineral oils marked with the viscosity class 15W-40 by different producers. The second group included semi-synthetic oils of winter viscosity class 10W but of different classes for summer conditions 40 and 60 by various producers. Fully synthetic oils with the designation of winter class 5W belong to the third group. They are differentiated in summer classes 30, 40 and 50 and were produced by many producers. Table 1 presents SAE viscosity index and Table 1 collects all the groups of oils selected for tests.

The tests of resistance to wear of cooperating surfaces in the presence of the tested engine oils in accordance with ASTM D2266-01 [2] were instrumented by the Four Ball Wear Tester Brown by Roxana Machine Works (Fig.1). The testing parameters were as follow:

- rotational speed: 1200 rpm ± 50 rpm,
- working temperature: 75°C ± 1,5°C,
- load: 400 N ± 20N,
- duration: 60 min ± 0,5 min.

The measure of anti-wear properties of the tested oil was the average diameter of defects on the bottom balls at constant, described testing parameters. The measurement of the diameters of the defects were carried out in directions that were perpendicular and parallel to the traces of wear using the measuring lamp. The result of the designation was the arithmetic mean of at least 5 designations which did not differ from their arithmetic mean more than 10%. During the tests the coefficient of friction was continuously recorded. The samples of fresh oil were collected from the commercial container.

Tab.1. Tested oils with the indication of SAE and API viscosity class.

No.	The name of the oil	API quality index	SAE viscosity index	Group
1	Elf Sporti SRI	SL	15W-40	1
2	Orlen Gas Lubro	SG	15W-40	
3	Quaker State HDX Universal	CF-4,CE CD/SH	15W-40	
4	Shell Helix Super	SJ/CF	15W-40	
5	Mobil Super S Semisynthetic Motor Oil	SL/CF	10W-40	2
6	Orlen Gas Semisynthetic	SG	10W-40	
7	Platinum RALLY Sport	SL/CF	10W-60	
8	Elf Evolution SXR	SL/CF	5W-30	3
9	Elf Excellium LDX	SL/CF	5W-40	
10	Elf Excellium	SG/CD	5W-50	

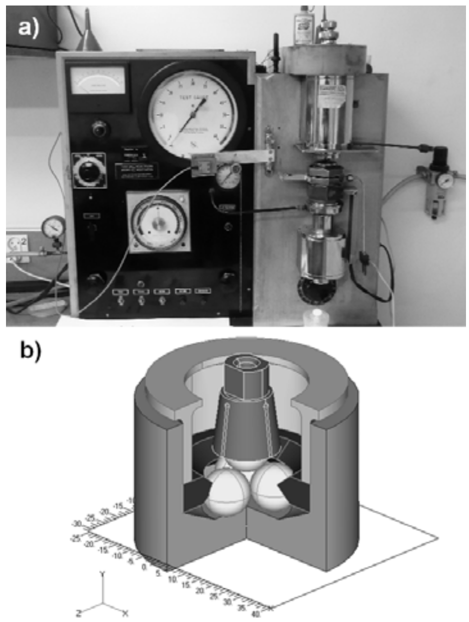

Fig.1. Four-ball testing machine by Roxana: a) main view, b) friction node

The viscosity tests of engine oils were carried out using the rotational rheometer Kinexus Pro by Malvern Instruments (Fig.2.) The rheometer is equipped with three controlled and configured independently systems. One of them is engine of low inertia and the system of air bearings. Such system allows for precise control of shear rate and stresses. Thus, it is possible to obtain continuous values of torque in all the testing range. The next system is a gap control system and measurement of normal force. Kinexus Pro combines sensitive normal force measurement system with precision of the measurement gap. The third system is the system of temperature control. Additionally, the temperature gradients in the sample are reduced by the Peltier system. Space Software enables creation of standard operating procedures, advanced data analyses and automated measurement sequences.

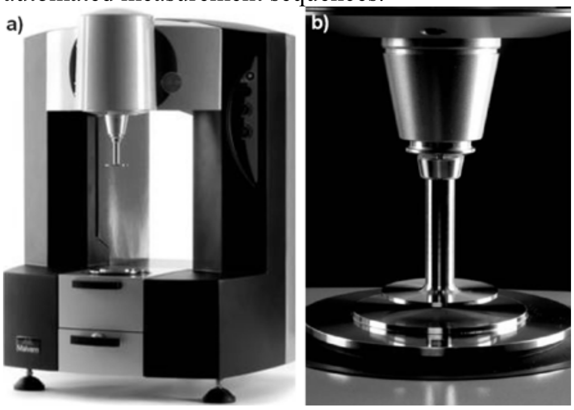

Fig. 2. Rotational rheometer Kinexus Pro: a) main view, b) testing node

The oil tests were carried out with the use of testing node PU20:Pl65 in the configuration of parallel tiles of diameters of 20mm and 65mm, in the mode with controlled shearing stress (Fig.2b.). The testing parameters were as follow:

- shearing stress 1 Pa,
- the range of temperature from -10°C to 10°C and from 70°C to 80°C , resolution 0,01°C,
- the height of gap 0,15mm, resolution 0,1μm,
- temperature-rise of 5°C/ min.

The curves showing the relationship of viscosity to temperature were determined for each type of oil in 5 measurement cycles in the temperatures mentioned above. For each test, the sample of fresh oil was collected from the commercial container. The determined points of the characteristics make the average of 5 tests. On the basis of the conducted analysis of variance, it was stated that the uncertainty of the test was $0{,}15 \cdot 10^{-3}$ Pa s. The values of standard deviation were not included in the charts so as to make them more clear.

3. RESULTS AND DISCUSSION

In the tribological tests it was stated that there is diversified resistance to wear of the tested friction nods depending on the kind of the engine oil (Fig.3). In the temperature of 75°C the wear defects of the tested oils stay in the range of 0,47mm – 0,67 mm. One also recorded coefficients of friction, which in the determined conditions were in the range of 0,44 – 0,50 (Fig.4).

The mineral oils 15W-40 are characterized by the wear defects in the range from 0,49 mm to 0,67 mm. In this group the values of defects are strongly diversified, although these oils are in the same viscosity class. The highest resistance to wear appeared in Orlen Gas Lubro 15W-40 from viscosity class SG which is lower than the rest of the oils of this group (Fig.3). In group 1, the course of the determined coefficients of friction forms in the range from 0,47 to 0,50. For this group, in the introductory phase of the course, clearly lower value of the coefficient of friction is observed, then there is an unstable period of rise and in the next test it has a stabilized value. In the case of the Shell Helix Super 15W-40 SJ/CF, the course of the coefficient of friction is characteristic. At the beginning, for 5 minutes, it has a value of 0,34 and then there occurs an unstable period of rise and after 20 minutes it stabilizes on the level of 0,49 (Fig 4.).

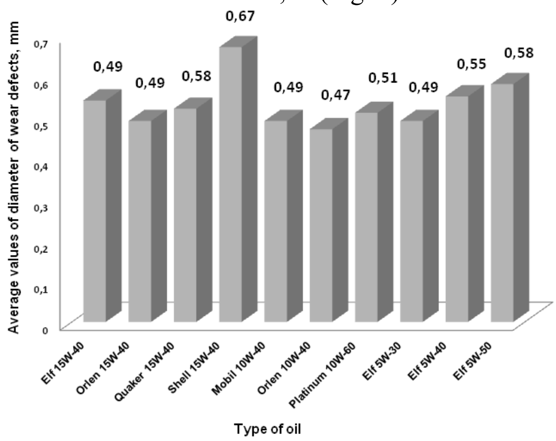

Fig. 3. Specification of wear defects of engine oils tested by ASTM D2266-01

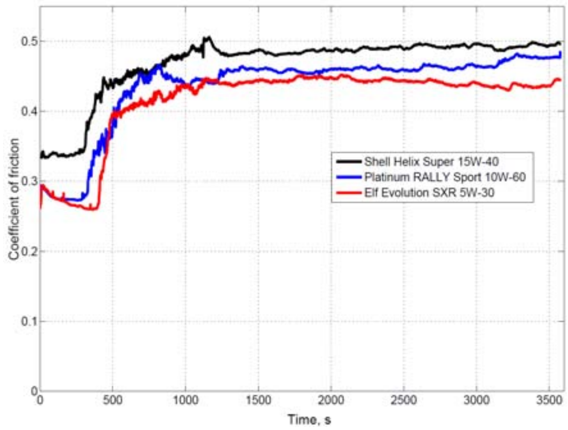

Fig. 4. Exemplary chart of coefficients of friction for mineral, semisynthetic and synthetic oils.

The oils of group 2 – semisynthetic, designated as 10W, are characterized by the similar values of the wear defects in the range from 0,47 mm to 0,51 mm. Orlen Gas Semisynthetic 10W-40, SG quality grade – lower than the rest of the oils of the group, showed the highest resistance to wear (Fig.3). In the second group the course of determined coefficients of friction stays in the range from 0,44 to 0,46. For this group of oils the course of coefficient of friction of Platinum RALLY Sport 10W-60 SL/CF is characteristic. First, for 6 minutes it has lower value of 0,28 and later an unstable period of rise happens and after 20 minutes it stabilizes on the level of 0,46 (Fig.4).

The oils from group 3 – synthetic of 5W designation have similar values of defects of wear in the range from 0,49 mm to 0,58 mm. The values of wear defects slightly rise together with the affiliation to the higher summer class. The greatest resistance to wear was noted in the case of Elf Evolution SXR 5W-30 staying in the highest viscosity class SL/CF (Fig.3). The course of the determined coefficients of friction includes in the range from 0,44 to 0,46. For this group of oils the course of the coefficient of friction for Evolution SXR 5W-30 SL/CF is characteristic. At the beginning, for seven minutes it has lower value of 0,26 and then an unstable period of rise takes place and after 20 minutes it stabilizes on the level of 0,44. (Fig.4.).

In all the tested groups of engine oils viscosity decreases together with the increase of temperature. At the temperature of -10°C viscosity values occur in the range from 1,118 Pa s to 3,168 Pa s; at 0°C it remains in the range from 0,565 Pa s to 1,521 Pa s and at 10°C they can be found in the range from 0,276 Pa s to 0,736 Pa s (Fig.5.). At the temperature of 75°C viscosity is placed in the range from 0,015 Pa s to 0,037 Pa s (Fig.6). The determined viscosity characteristics prove the affiliation to the SAE viscosity index. However, there are differences among particular oils.

Operating requirements are often divergent with physiochemical parameters which result changing depending on the tribological force. The parameters of engine oils result from the structure of oil base and used additives. The same oil should maintain fluidity at sub-zero temperatures to enable cold start-up and restrict wear in winter conditions and should keep viscosity in the definite range of values at high temperatures in order to preserve proper lubrication of motive nodes and simultaneously cause minimal losses to wear [9,15].

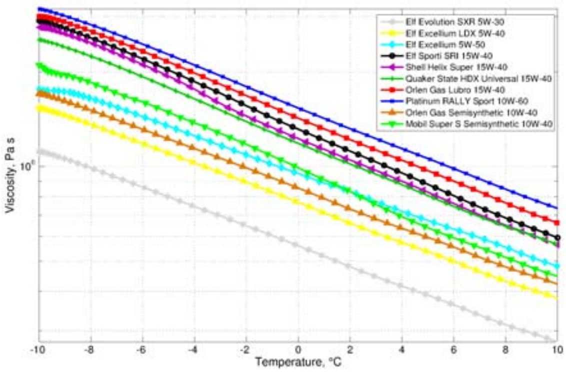

Fig. 5. The characteristics of viscosity of engine oils in the range of sub-zero and low temperatures

Viscosity of oils from group 1 of designation 15W-40 at temperature of -10°C takes values from 2,530 Pa s to 3,001 Pa s; and, correspondingly, at 0°C it is from 1,164 Pa s to 1,446 Pa s; at 10°C viscosity can be found in the range from 0,564 Pa s to 0,662 Pa s (Fig.5.). The oil called Quaker State HDX UNIVERSAL 15W-40 has the best viscosity parameters at sub-zero and low temperatures and Orlen Gas Lubro 15W-40 has the worst ones. The most visible differences of viscosity occur at sub-zero temperatures and while the temperature increases characteristics draw together. Viscosity of oils from the first group at 75°C remain in the range from 0,023 Pa s to 0,027 Pa s. (Fig.6.).

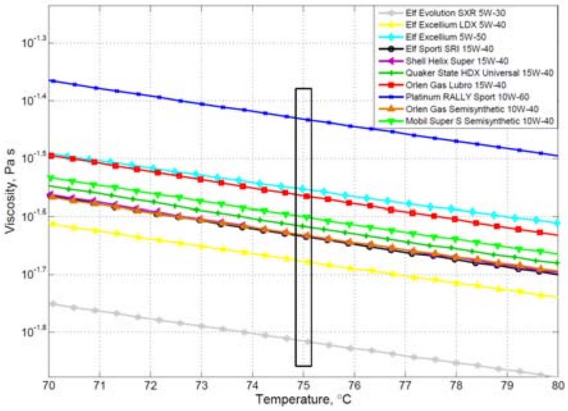

Fig.6. The characteristics of viscosity of engine oils in the referential temperature.

The analysis of viscosity-temperature relationship for oils from group 1 shows that the oil Quaker State HDX UNIVERSAL 15W-40 has optimal viscosity characteristics – preserves low viscosity at sub-zero temperatures which does not also drop too drastically at high temperatures. The highest values of viscosity obtained in the range from -10°C to 100°C are characteristic to the oil Orlen Gas Lubro 15W-40 [14].

Viscosity of oils from groups 2 and 3 having increased SAE viscosity index 5W and 10W in winter conditions at -10°C can be found in the range from 1,118 Pa s to 3,168 Pa s; at 0°C: from 0,565 Pa s to 1,521 Pa s; and at 10°C: from 0,276 Pa s to 0,730 Pa s (Fig.5.). To estimate tribological, diagnostic and operating parameters, structural viscosity of oils were compared at sub-zero and low temperatures. Viscosity of oils from groups 2 and 3 were arranged in three areas. The lowest viscosity is characteristic to the oil Elf Evolution SXR 5W-30. In the second area, in ascending order, one can indicate the oil called Elf Excellium LDX 5W-40, Orlen Gas Semisynthetic 10W-40, Elf Excellium 5W-50 and Mobil Super S Semisynthetic 10W-40. The oil Platinum Rally Sport 10W-60 is placed in the third area of the highest viscosity values at sub-zero and low temperatures. The greatest differences of viscosity occur at sub-zero temperatures and, with increasing temperature the characteristics draw together. It could be thought that in the exploited friction knot, especially in the conditions of fluent and mixed friction, the smallest wear of motive nodes as well as the smallest losses to friction in conditions of cold start-up will occur in the case of lubrication with the oil Elf Evolution SXR 5W-30. Viscosity of oils from the group 2 and 3 at 75°C are placed in the range from 0,015 Pa s to 0,037 Pa s. Viscosity characteristics of oils from groups 2 and 3 at high temperatures are set in accordance with the indications of SAE viscosity index for summer conditions: 30, 40, 50 and 60. The oil Elf Evolution SXR 5W-30 has the smallest viscosity at high temperatures.

Table 2 presents the comparison of rheological parameters determined in tests with parameters of the characteristics of the product given by oil producers in accordance with the Regulation (WE) no 1907/2006 of the European Parliament and the Council concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). What is more, the determined in the previous tests kinematic viscosity values at 100°C were related to the parameters given by the J300 classification [14]. From the comparison of results of tests of oil viscosity to catalog parameters one can conclude that the determined kinematic oil viscosity values at 40°C and 100°C are close to those corresponding viscosity values presented by the producer. Moreover, on the basis of obtained results of viscosity tests it can be stated that only the oil called Elf Evolution SXR 5W-30 does not fulfill conditions for kinematic viscosity at 100°C, as described in the classification J300.

Tab. 2. The comparison of rheological parameters of tested oils with catalog parameters and the estimation of their affiliation to J300 classification.

No.	The name of the oil	Producer's catalog parameters				Investigated the rheological parameters				Fulfillment of the kinematic viscosity according to J300
		SAE viscosity index	Density in 15°C, kg/m^3	Kinematic viscosity mm^2/s		Dynamic viscosity Pa s		Kinematic viscosity mm^2/s		
				40°C	100°C	40°C	100°C	40°C	100°C	
1	Elf Evolution SXR	5W-30	855	51	9,84	0,0545	0,0078	63,7	8,8	NO
2	Elf Excellium LDX	5W-40	849	85	14	0,0749	0,0112	88,2	13,2	YES
3	Elf Excellium	5W-50	885	115	18,2	0,0968	0,0146	109,4	16,5	YES
4	Elf Sporti SRI	15W-40	881	104,8	14	0,0921	0,0130	104,5	14,8	YES
5	Shell Helix Super	15W-40	885	105,4	13,9	0,0907	0,0119	102,5	13,4	YES
6	Quaker State HDX Universal	15W-40	887	110,3	14,5	0,0975	0,0124	109,9	14	YES
7	Orlen Gas Lubro	15W-40	890	-	15,9	0,1068	0,0136	120	15,3	YES
8	Platinum RALLY Sport	10W-60	860	-	21,9 – 26,1	0,1373	0,0191	159,6	22,2	YES
9	Orlen Gas Semisynthetic	10W-40	870	-	15,3	0,0832	0,0123	95,6	14,1	YES
10	Mobil Super S Semisynthetic	10W-40	872	108	14,4	0,0877	0,0129	100,6	14,8	YES

The estimation of engine oils included the lubricity and viscosity tests at temperature 75°C as well as the measurement of rheological properties at sub-zero and low temperatures. The substantial sense of this evaluation was based on the verification whether the oil provides optimal conditions of lubrication during start-up at sub-zero and low temperatures and investigation of resistance to wear of elements working with this oil at sliding friction at referential temperatures of operation. The research allowed to answer the question of what wear of surface occurs at sliding friction when using engine oil with low resistance to motion. The method made it possible to indicate Elf Evolution

method made it possible to indicate Elf Evolution SXR 5W-30 as mostly preferred for cars exploited in conditions of frequent start-ups.

4. CONCLUSIONS

On the basis of the conducted tests of engine oils the following conclusions can be stated:

1. The elaborated method allows for the comparison of oils designed for application and at the same time to diagnose how the oils will secure the motive nodes in the conditions of operation.

2. All the tested mineral oils, semisynthetic and synthetic ones are characterized by the similar resistance to wear. Only Shell Helix Super 15W-40 SJ/CF stands out as it shows the worst resistance to wear and the highest resistance to motion.
3. Due to the resistance to wear at referential temperature and with regard to the lowest coefficient of friction in the conditions of start-up as well as stable and low coefficient of friction in lubricity tests it can be concluded that Elf Evolution SXR 5W-30 SL/CF will behave in the best way in the conditions of operation.
4. The progress that took place in the new generation of engine oils on semisynthetic and synthetic bases counteracts excessive wear of elements at variable conditions of work and simultaneously decreases the resistance to motion in the whole range of operation.

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