Method for monitoring evaluation of dominant influence processes of oxidation and temperature destruction on basic indications of bodies of motor oils

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Abstract. The When the internal combustion engine is operated on friction surfaces, the processes of oxidation, temperature destruction and chemical reactions of metals with their products and additives proceed simultaneously. However, the dominant influence of one of the processes on the physico-chemical and anti-wear properties of oils has not been adequately studied. Therefore, the purpose of the present studies is to search for a new criterion that takes into account the optical properties of thermostated oil, viscosity index and antiwear properties. The experimental results of the empirical test of the thermooxidative stability of motor oils of various base bases, determined by the ratio of the product of optical density to the decimal logarithm of the viscosity index to the arithmetic mean of the wear spot diameter, are presented. It has been established that the base base of engine oils and test temperature has a different effect on the empirical criterion of thermooxidative stability.

1. Introduction
During the operation of the tribosystem, under the influence of high temperature, the oil undergoes significant aging, the content of additives decreases, which leads to a decrease in the performance of the oil [1-7]. Numerous instrumental methods are used to assess the condition of motor oil, which allow one to determine thermo-oxidative stability by changing viscosity, optical properties, acidity, dielectric loss tangent, corrosion activity, volatility, amount of deposits and other indicators. However, the influence of these indicators on the tribotechnical characteristics of oxidized motor oils has not been sufficiently studied. In addition, it was found that motor oils are thermostatically controlled in the study of temperature resistance and thermo-oxidative stability. The processes of oxidation and thermal destruction occur simultaneously, but with different intensities. However, the dominant influence of one of the processes on the physicochemical and antiwear properties of motor oils has not been studied enough.

To assess the dominant effect of oxidation products or temperature deterioration on the antiwear properties of oils, an analysis of the work in this area is carried out. CV made a significant contribution to the study of processes occurring during frictional contact. Kragelsky B.I. Kostetskiy, V.G. Vinogradov R.M. Matveevsky I.A. Buyanovsky Yu.S. Zaslavsky I.S. Gershman A.S. Kuzharov I.A. Boucher G.I. Shor A.S. Akhmatov et al. However, in these works, when evaluating the antiwear properties, all processes occurring at the friction contact at the same time were taken into account. Therefore, the search for new methods is aimed at establishing quantitative indicators of the predominant effect of one of the processes on the physicochemical and antiwear properties of oils.

This paper presents a control method for assessing the dominant influence of oxidation processes and temperature destruction on the main indicators of motor oils (resource, antiwear properties and
viscosity-temperature characteristics). were evaluated at constant friction parameters of oxidized and thermostated oils in the temperature range from 170 to 180 °C, which made it possible to establish differences in the effect of oxidation products and temperature destruction on the antiwear properties of oils, to substantiate a general criterion of antiwear properties, taking into account the concentration of oxidation products or the temperature of destruction at the nominal areas of friction contact, and propose a generalized indicator of antiwear properties, taking into account the rate of change of antiwear criteria properties of oxidized and thermostatically controlled oils, to establish the dominant effect of oxidation products or thermal destruction on the wear mechanism.

The monitoring methodology for assessing the dominant influence of oxidation processes and temperature destruction on the main indicators of motor oils, consisting of four separate methods, involves the use of measuring instruments such as a device for thermostating of oils with and without stirring, a photometer for direct photometry, a low-volume viscometer, centrifuge, three-ball friction machine with ball-cylinder friction scheme, scales. The scheme of the complex control method is presented in figure 1.

![Figure 1. Monitoring method for assessing the dominant influence of oxidation processes and temperature destruction on the main indicators of motor oils.](image)

The methodology for testing thermal oxidative stability of motor oils involves two stages. At the first stage, samples of constant weight oils (100 ± 0.1 g) were thermo-statically tested at temperatures of 180 and 170 °C with stirring. At constant time intervals (8 h), samples of oxidized oil were taken for direct photometry and determination of optical density, viscosity index and volatility.

The mass of evaporated oil was determined by the formula

\[ \Delta G = G_2 - G_1, \]

where \( G_1 \) and \( G_2 \) – mass of oil sample with a glass before and after temperature control, g.
For the direct photometric method, a part of the sample (2 g) was taken with the subsequent determination of the optical density $D$ at a photometric layer thickness of 2 mm according to the formula

$$D = \lg \frac{300}{P} \quad (1)$$

where $300$ – preset photometer current with an empty cell, $\mu$A; 
$P$ – photometer readings during photometry of thermostated oils, $\mu$A.

To recalculate the viscosity index according to GOST 25371-97 [8], a portion of the sample of oxidized oil (9 g) was taken and used to measure the kinematic viscosity at 40 and 100 °C.

The second stage involved the testing of oils using the same technology, but at certain optical densities, an additional sample of oxidized oil was taken for testing on a three-ball friction machine, and the remaining part of the oil was added to the initial value of 100 ± 0.1 g.

The test procedure on a three-ball friction machine provided for tests with constant friction parameters: load - 13 N; sliding speed - 0.68 m/s, oil temperature in the volume - 80 °C, test time - 1.5 hours. The antiwear properties of thermostated lubricants were estimated by the arithmetic mean of the diameter of the wear spot on those balls from two parallel experiments [9-12].

The temperature resistance test method for engine oils also includes two steps. At the first stage, samples of constant weight oils (100 ± 0.1 g) were thermostated at temperatures of 180 and 170 °C without stirring at atmospheric pressure with vapor condensation and condensate drain. At constant time intervals (8 h), samples of thermostated oil were taken for direct photometry and determination of optical density, viscosity and volatility (the procedure for determining the values of these parameters is presented above).

The second stage involved the testing of oils using the same technology, but at certain optical density values, a thermostatic oil sample was additionally taken for testing on a friction machine, and the remaining part of the oil was added to the initial value of 100 ± 0.1 g.

The results of experimental studies were processed by the methods of mathematical statistics and regression analysis using «Advanced Grapher» computer programs.

In order to assess the dominant influence of oxidation processes and temperature destruction, the following were determined:

- coefficient of dominant influence $C_{DI}$, determined by the ratio of the rates of change of the criteria for temperature resistance and thermo-oxidative stability, allowing you to reasonably choose more heat-resistant motor oils

$$C_{DI} = \frac{\alpha_{TR}}{\alpha_{TOS}} \quad (2)$$

where $\alpha_{TR}$ и $\alpha_{TOS}$ – parameters characterizing the rate of change of criteria of temperature resistance $C_{TR}$ and thermo-oxidative stability $C_{TOS}$.

- a generalized indicator of antiwear properties (GIAP) of thermostatically controlled oils, allowing to assess the dominant effect of thermal decomposition products on the tribological characteristics of the tested motor oils

$$GAIP = \frac{\alpha_{APTR}}{\alpha_{APTOS}} \quad (3)$$
where \( \alpha_{\text{APTR}} \) and \( \alpha_{\text{APTOS}} \) – parameters characterizing the average rate of change of the criterion of antiwear properties \( C_{\text{AP}} \) by concentration of decomposition and oxidation products, respectively.

- process influence coefficient \( C_{\text{PI}} \) thermostatically controlled oils to assess the dominant influence of oxidation processes or thermal destruction on the basic performance properties of motor oils, calculated by the formula

\[
C_{\text{PI}} = \frac{\alpha_{\text{OPTOS}}}{\alpha_{\text{OPTOS}}},
\]

(4)

the formula contains parameters characterizing the average rate of change of the criterion of operational properties \( C_{\text{PI}} \) on the concentration of destruction and oxidation products, respectively.

If the value of these coefficients / indicators is less than 1, then the oxidation processes dominate, and if more than 1, then the processes of temperature destruction.

2. The results of the study and their discussion

Functional dependences of the indicators of thermal oxidative stability and temperature resistance, criteria of thermal oxidative stability, temperature resistance, anti-wear and operational properties and the results of their regression analysis of engine oils of various basic bases (mineral motor oil ZIC HIFLO 10W-40 SL, partially synthetic Castrol Magnatec 10W-40 R SL / CF and synthetic ALPHA’S 5W-40 SN) are presented in tables 1 and 2 [13-17].

| Table 1. Test results of engine oils of various basic bases during oxidation. |
|---------------------------------|---------------------------------|---------------------------------|
| Indicator | Mineral engine oil Zic HIFLO 10W-40 SL | Partially synthetic engine oil Castrol Magnatec 10W-40 R SL / CF | Synthetic engine oil ALPHA’S 5W-40 SN |
| Potential resource on \( D = 0.5 \) units, h |
| at 180 °C | 50 | 69 | 76 |
| at 170 °C | 101 | 145 | 163 |
| Coefficient of relative viscosity \( C_{\mu} \) |
| at 180 °C (max/min) | (1,167/1) | (1/0.652) | (1/0.8) |
| at 170 °C (max/min) | (1,169/1) | (1/0.84) | (1/0.849) |
| Evaporation, g |
| for 56 hours at 180 °C | 12.05 | 6.18 | 9.09 |
| for 112 hours at 170 °C | 10.84 | 9.8 | 10.72 |
| Indicator \( I_{\text{TOS}} \) |
| for 56 hours at 180 °C | 0.693 | 0.386 | 0.496 |
| for 112 hours at 170 °C | 0.668 | 0.481 | 0.531 |
| The viscosity index of commercial oil, units | 98 | 107.13 | 140 |
| The viscosity index of oxidized oil, units |
| at 180 °C (max/min) | (105.25/98) | (107.72/92.88) | (140/106.29) |
| at 170 °C (max/min) | (105.87/98) | (109.42/98.98) | (140/105.9) |
| Criterion \( C_{\text{TOS}} \) |
| at 180 °C | \( C_{\text{TOS}} = 104.568 \cdot D \) | \( C_{\text{TOS}} = 93.136 \cdot D \) | \( C_{\text{TOS}} = 113.498 \cdot D \) |
| at 170 °C | \( C_{\text{TOS}} = 105.017 \cdot D \) | \( C_{\text{TOS}} = 102.646 \cdot D \) | \( C_{\text{TOS}} = 120.459 \cdot D \) |
| Wear parameter, mm | (0.323/0.23) | (0.35/0.255) | (0.266/0.25) |
| Indicator                           | Mineral engine oil Zic HIFLO 10W-40 SL | Partially synthetic engine oil Castrol Magnatec 10W-40 R SL/CF | Synthetic engine oil ALPHA’S 5W-40 SN |
|------------------------------------|---------------------------------------|---------------------------------------------------------------|---------------------------------------|
| Evaporation, g                     |                                       |                                                               |                                       |
| for 56 hours at 180 °C             | 3,91                                  | 3,96                                                          | 4,46                                  |
| for 112 hours at 170 °C            | 4,54                                  | 6,71                                                          | 5,41                                  |
| The viscosity index of commercial oil, units | 98                                    | 107,13                                                        | 140                                   |
| The viscosity index of thermostated oil, units |                                    |                                                               |                                       |
| at 180 °C (max/min)                | (100,15/95,22)                        | (113,47/105,2)                                               | (140/113,9)                           |
| at 170 °C (max/min)                | (105,23/98)                           | (112,42/104,61)                                             | (140/114,7)                           |

Note: the numbers standing through the fraction sign (/) indicate the maximum and minimum values, respectively.
Criterion $C_{TR}$

\[
\begin{align*}
C_{TR} &= 99,589 \cdot D & C_{TR} &= 112,157 \cdot D & C_{TR} &= 122,786 \cdot D \\
\text{at 180 °C} & & \text{at 170 °C} & & \text{at 180 °C} & & \text{at 180 °C} \\
C_{TR} &= 99,55 \cdot D & C_{TR} &= 107,396 \cdot D & C_{TR} &= 126,164 \cdot D
\end{align*}
\]

Wear parameter, mm

\[
\begin{align*}
\text{at 180 °C (max/min)} & : (0,263/0,23) & \text{at 170 °C (max/min)} & : (0,276/0,23) \\
\text{at 180 °C (max/min)} & : (0,295/0,248) & \text{at 170 °C (max/min)} & : (0,309/0,255)
\end{align*}
\]

Criterion $C_{AP}$, mm$^{-1}$

\[
\begin{align*}
C_{AP} &= 3,177 \cdot D & C_{AP} &= 3,461 \cdot D & C_{AP} &= 3,456 \cdot D \\
\text{at 180 °C} & & \text{at 180 °C} & & \text{at 180 °C} \\
C_{AP} &= 3,628 \cdot D & C_{AP} &= 4,241 \cdot D & C_{AP} &= 3,231 \cdot D
\end{align*}
\]

Criterion $C_{OP}$

\[
\begin{align*}
C_{OP} &= 7,606 \cdot D & C_{OP} &= 7,094 \cdot D & C_{OP} &= 7,222 \cdot D \\
\text{at 180 °C} & & \text{at 180 °C} & & \text{at 180 °C} \\
C_{OP} &= 7,384 \cdot D & C_{OP} &= 8,519 \cdot D & C_{OP} &= 6,876 \cdot D
\end{align*}
\]

Test results of engine oils of various basic bases during oxidation.
Comparative assessment of the dominant influence of oxidation processes or temperature destruction of oils by the coefficient of the dominant influence $C_{pI}$, generalized indicator of antiwear properties (GAIP) and the coefficient of influence of processes $C_{pI}$ are presented in table. 3.

Table 3. Comparative assessment of the dominant influence of oxidation processes or thermal destruction of oils of various basic bases.

| Indicator | Mineral engine oil Zic HIFLO 10W-40 SL | Partially synthetic engine oil Castrol Magnatec 10W-40 R SL/CF | Synthetic engine oil ALPHA’S 5W-40 SN |
|-----------|--------------------------------------|-------------------------------------------------|--------------------------------------|
| Generalized indicator of antiwear properties (GAIP), units | | | |
| at 180 °C | 1,187 | 0,977 | 0,861 |
| at 170 °C | 1,076 | 1,28 | 0,999 |
| Coefficient $C_{pI}$, units | | | |
| at 180 °C | 1,21 | 1,016 | 0,883 |
| at 170 °C | 1,083 | 1,279 | 0,999 |

3. Conclusion
The developed monitoring method for assessing the dominant effect of oxidation processes and thermal degradation on the main indicators of motor oils, which allows one to obtain information on changes in the properties of motor oils during thermostating and oxidation, to determine the dominant
effect of oxidation products or thermal degradation on the potential resource, tribological and viscosity-temperature characteristics of motor oils.

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