Research results of anti-wear properties of mineral and semi-synthetic motor oil

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Abstract. The object of research is influence of temperature and destruction products on boundary layers formation located on rubbing parts. There are research results of anti-wear properties of mineral and partially synthetic motor oil using methods for determining parameters such as absorption coefficient of the light flux, viscosity, and friction parameters. As result there is analyze of experimental data, absorption curve, that are showing anti-wear properties of lubricants, also proposed criterion that is showing concentration of destruction products on the nominal area of friction contact.

1. Introduction

As lubricants can't unlimited absorb thermal energy, excess is absorbed by generated oxidation products, vaporized and destruction products. In this connection temperature on start of conversion process and parameters of this can show temperature resistance index that can identify lubricants.

For each oil grade defined current magnitude in each temperature of the test, it depends on electric conductivity in boundary layer that separate frictional area. These can be layers such as:

- adsorption layer – layers generate in absence destruction products in oil with low temperature;
- chemisorption layer – layers generate as a result of chemical reaction at medium temperature of activated molecules of additives with metal surface of details;
- modified layer – layers generate at high temperature of the test.

To increase the resistance of surfaces of details of mechanisms and machines, various additives containing compounds of fluorine, sulfur, chlorine and phosphorus in the amount of 5-10% are added to lubricants. The effect of additives is as follows: at high temperature and high pressure, all of the above compounds between the rubbing surfaces decompose and react with the part, in the process a protective film of phosphate or iron sulfate is formed, which prevents further temperature rise and reduces friction [1-3].

From the above it can be concluded that the temperature in the contact area plays an important role in the process of friction and wear. Therefore, it is proposed to investigate the effect of temperature and degradation products on the formation of boundary layers on the surfaces of rubbing parts.
2. Research methods and results

Research procedure included the use of such devices as: device for thermostating of fuels and lubricants, viscometer, photometric device, electronic scales, a three-ball machine with a friction scheme (TMT) "ball-cylinder" [4-6].

The procedure involves testing a constant mass oil sample (80±0.1 g) in a heat-resistant glass beaker for a constant time (8 hours) at certain selected temperatures. Tests are carried out in the temperature range from 160 to 280 °C every 20 °C, and each time the commercial oil is tested. Tests are carried out at atmospheric pressure without mixing the sample, which eliminates oxidation processes and provides the most complete destruction of the base of the oil and additives available in the oil. A portion of the sample (20±0.1 g) is then taken for testing on TMT with the scheme of friction as «ball-cylinder».

The resistance of degradation oils was defined by the change in the absorption coefficient of the light flux $K_a$ and the coefficient of relative viscosity $K_\mu$. Coefficient $K_a$ was determined on a photometric device with a thickness of 2 mm photometric layer, and the relative viscosity – as the ratio of the viscosity of the oil after heat treatment to the viscosity of the commercial oil. Friction parameters were: load – 13N, sliding speed – 0.68 m/s, test temperature – 80 °C, test time – 2 hours, contact current – 100 µa. For research was selected mineral motor oil M10-Г2к and partly synthetic motor oil Idemitsu 10W-40 SN/CF.

The results of photometry of thermostatic mineral motor oil are shown in figure 1.

![Figure 1](image_url)

**Figure 1.** The dependence of absorption coefficient the light flux $K_a$ temperature control mineral motor oil M10-Г2к.

The dependence of changes in the optical properties of motor oils on temperature was estimated by the absorption coefficient of the light flux $K_a$. Two characteristic temperature regions in which the character of change of $K_a$ coefficient is different are established. The first temperature range up to $T_1$ (240 °C) is characterized by a linear varying in the $K_a$ coefficient and is described by the regression equation

$$
\hat{E}_a^I = 4.8\hat{O} \cdot 10^{-4} - 0.05,
$$

where $T$ – temperature of the test, °C.

In the second temperature range from $T_1$ (240 °C) there is a steep increase in the absorption coefficient of the light flux, which is characterized by the formation of degradation products with a higher optical density (secondary), which began to form in the first region. The region from $T_1$ is described by the regression equation

$$
\hat{E}_a^{II} = 36.8\hat{O} \cdot 10^{-4} - 0.815
$$

where $T$ – temperature of the test, °C.

The research of the effect of degradation products on viscosity (figure 2) showed that the dependence is described by a polynomial of the 3rd order:
\[ \hat{E}_\mu = 1.973 \hat{E}_a^3 \cdot 10^{-6} - 0.001 \hat{E}_a^2 + 0.234 \hat{E}_a - 13.516 \]

Figure 2. The dependence of the relative viscosity coefficients on the absorption coefficients of the light flux during thermostating of motor mineral oil M10-Г2к.

In the analysis of the dependence of wear spot diameter on the temperature control the temperature of the motor oil (figure 3) were taken into account the impact of degradation products, the number of which increased with increasing temperature thermostat.

Figure 3. Dependence of the diameter of the wear spot on the temperature of the temperature control of motor mineral oil M10-Г2к.

The dependence of the wear spot diameter on the coefficient \( K_a \), which characterizes the number of degradation products, is shown in figure 4.

It is established that the concentration of degradation products, characterized by the absorption coefficient of the light flux, affects the diameter of the wear spot, therefore, coefficient \( P \) is proposed as an estimate of the anti-wear properties of motor oils, defined by the expression

\[ P = \frac{\hat{E}_a}{U} \]

Figure 4. The dependence of the diameter of the wear spot on the absorption coefficient of the light flux of the motor mineral oil M10-Г2к.

This criterion (figure 5) characterizes the concentration of degradation products on the nominal area of the friction contact.
Figure 5. The dependence of the criterion $P$ on the absorption coefficient of the light flux $K_a$ when thermostating mineral motor oil M10-$\Gamma_2\kappa$.

Regressive dependence of the criterion $P$ on the coefficient $K_a$ has the form

$$P = 4.919\hat{E}_a - 0.037.$$  \hspace{1cm} (5)

When thermostating motor mineral oil M10-$\Gamma_2\kappa$ in the temperature range from 160 to 280 °C set one critical temperature $T_1$ (240 °C), at which the absorption coefficient of the light flux $K_a$ and slightly viscosity steep increase.

The dependence of wear spot diameter from the absorption coefficient of the light flux $K_a$ showed that with the increase of the coefficient $K_a$, the wear is reduced, due to the fact that when temperature control of the motor oil is formed more durable molecules that remain on the surface of friction parts and prevent further wear.

The results of photometry of thermostatic mineral semi-synthetic oil are shown in figure 6.

Figure 6. The dependence of the absorption coefficient of the light flux of $K_a$ on the temperature of the thermostating semi-synthetic motor oil Idemitsu 10W-40 SN/CF.

Two characteristic temperature regions in which the character of change of coefficient $K_a$ is different are established. The first temperature range up to $T_1$ (200 °C) is characterized by a linear varying in the $K_a$ coefficient and is described by the regression equation

$$\hat{E}_a^I = 0.001\hat{T} - 0.199, \quad (6)$$

$T$ – temperature of the test, °C.

In the second temperature range from $T_1$ (200 °C), as in the case of mineral oil M10-$\Gamma_2\kappa$, there is a steep increase in the absorption coefficient of the light flux, which is also characterized by the formation of degradation products with a higher optical density. The region from $T_1$ is described by the regression equation

$$\hat{E}_a^II = 0.017\hat{T} - 3.465, \quad (7)$$

$T$ – temperature of the test, °C.

The research of the effect of degradation products on viscosity (figure 7) showed that the dependence is described by a polynomial of the 3rd order.
\[ \hat{E}_\mu = 1.973\hat{E}_a^3 \times 10^{-6} - 0.001\hat{E}_a^2 + 0.234\hat{E}_a - 13.516, \]  

(8)

\(K_a\) - absorption coefficient of the light flux.

Analyzing the dependence of the diameter of the wear spot on the temperature of the motor oil thermostating (figure 7), the factor of influence of degradation products was taken into account, the number of which increased with an increase in the temperature of the thermostating. The dependence of the wear spot diameter on the coefficient \(K_a\), which characterizes the number of degradation products, is shown in figure 8.

It is established that the wear spot diameter is affected by the concentration of degradation products, characterized by the absorption coefficient of the light flux, so as the evaluation of anti-wear properties of motor oils suggested coefficient \(P\) defined as (4).

**Figure 7.** The dependence of the wear spot diameter on the thermostating temperature of semi-synthetic motor oil Idemitsu 10W-40 SN/CF.

**Figure 8.** The dependence of the diameter of the wear spot on the absorption coefficient of the light flux of semi-synthetic motor oil Idemitsu 10W-40 SN/CF.

This criterion (figure 9) characterizes the concentration of degradation products on the nominal area of the friction contact.

**Figure 9.** The dependence of the criterion \(P\) on the absorption coefficient of the light flux of \(K_a\) when thermostating semi-synthetic motor oil Idemitsu 10W-40 SN/CF.

Regressive dependence of the criterion \(P\) on the coefficient \(K_a\) has the form

\[ P = 3.041\hat{E}_a + 0.019, \]  

(9)

\(K_a\) - absorption coefficient of the light flux.

Thermostating semi-synthetic motor oil Idemitsu 10W-40 SN/CF in the temperature range from 160 to 260 °C, one critical temperature \(T_1\) (200 °C) is set, at which the absorption coefficient of the light flux began to increase steeply, due to the discharge of excess thermal energy;

The dependence of wear spot diameter from the absorption coefficient of the light flux \(K_P\) showed that with the increase of the coefficient \(K_a\), which characterizes the concentration of degradation
products, wear increases, due to the fact that when the motor oil temperature control the decomposition of additives added to the oil that prevent the formation of chemisorption membrane on the surface of friction details.

3. Conclusions
Based on the obtained research results, it is possible to conclude the dependence of the oil on the temperature regime. The main disadvantage of the oil can also be considered low wear resistance, changing when the sample is heated, which in turn carries the risk of failure and reduce the service life of the engine.

References
[1] Garkunov D N, Dyakin S I and Kurlov O N 1982 Selective transport in heavily loaded friction units (Moscow: Engineering) p 207
[2] Matveevsky R M 1971 Temperature resistance of boundary lubricating layers and solid lubricant coatings during friction of metals and alloys (Moscow: Science) p 227
[3] Buyanovsky I A 2003 The use of the kinetic approach to describe the boundary lubrication process Friction and wear 24 313–21
[4] Petrov O N 2015 Methods for monitoring and diagnosing the operational properties of lubricating oils Monograph (Krasnoyarsk: Siberian Federal University) p 152
[5] Kovalsky B I, Bezborodov Yu N, Malysheva N N and Shram V G 2012 The method for determining the temperature resistance of motor oils RF Patent 2,471,187 27 Dec 2012
[6] Kovalsky B I, Malysheva N N, Tarasov E V and Dyakov S A 2013 The test results semi synthetic motor oil BIZOL DIESEL ULTRA 10W-40 CJ-4/SL Proceedings of Tomsk Polytechnic University. Engineering of geo-resources 7 151–6