The results of the research of motor oils by the method of predicting indicators of thermal-oxidation stability

Yu N Bezborodov¹, N N Lysyannikova¹, A A Kirpichenko¹, A V Lysyannikov¹, M A Kovaleva¹ and A V Egorov²

¹ Siberian Federal University, 82 Svobodny Avenue, Building 6, 660041, Krasnoyarsk, Russia
² Volga State University of Technology, 3 Lenin Square, 424000, Yoshkar-Ola, Russia

E-mail: Nataly.nm@mail.ru

Abstract. The results of a study of the thermal-oxidation stability of motor oils are presented. The experimental data were obtained and analyzed by means of regression analysis, and graphical dependencies were constructed that clearly demonstrate the reaction of the lubricant to changing environmental conditions and with the help of which it was established that it is possible to determine the temperature of the onset of oxidation processes and temperature conversions, as well as their critical temperatures. As a criterion for evaluating thermal-oxidation stability, a coefficient of thermal-oxidation stability is recommended, taking into account the optical density and volatility of the oil. It shows the effectiveness of the method of predicting the performance indicators of a lubricant among existing research techniques.

1. Introduction
During the variety of engine models and various operating conditions, issues of selection and use of lubricants to ensure high operational reliability and durability are relevant. A variety of requirements are imposed on the quality of the motor oil, reflecting the interests of many industries. Therefore, the study of the laws of conducting motor oils in conjunction with the nature of the work and the technical condition of the engines is very important to increase the efficiency of their use in the operation of equipment.

Indicators characterizing the properties of lubricating oils are of great importance for controlling their quality in production and research. They are also important for evaluating the suitability of oils for use directly in the engine. The reliability, durability and efficiency of the engine will largely depend on how successful and accurate the method for determining the quality of lubricating oil is.

There are methods of controlling lubricants to determine the mass of solid contaminants, regulated by GOSTs, optical, microscopic, spectral methods, water content methods, acoustic [1-3], photometric methods for evaluating thermal-oxidation stability, including heating the lubricant in the presence of air, mixing, photometric evaluation of light intensity and determination of parameters for evaluating the oxidation process and others for determining the PI (operational properties of oils) [4-8].

The objective is to evaluate the effectiveness of the method of the prediction performance thermal-oxidation stability of lubricants.
2. Method and results of research

The method includes the test procedure, time and volume of the test operating environment. Work on each research instrument (a device for determining thermo-oxidative stability, a photometer, a small viscometer) is performed in the established sequence, which is repeated from test to test.

Figure 1 shows a block diagram of a method for research and predicting the thermo-oxidative stability of lubricants.

![Figure 1. The block diagram of the methodology for research and prediction of thermo-oxidative stability of motor oils.](image)

To test there was taking of motor oil sample weighing 100 g ± 0.1. Test temperature was varied from 160 to 180 °C (with an interval of 10 °C) and maintained automatically. After each test, after a certain period of time (8 hours), an oil sample was taken to evaluate its current properties. The sample was weighed on a scales to determine the volume of evaporated oil (volatility), then the optical properties of the oil were measured using a photometer (thickness of the photometric layer 2 mm) and then the optical density and thermal-oxidation stability coefficient were determined [9].

The method for predicting the indicators of thermal-oxidation stability is based on the construction of graphical dependencies that allow one to determine the oxidation onset temperature and temperature conversions occurring in motor oil and the critical temperatures of these processes. In addition to the above, the method can significantly reduce the test time [10].

For research, we chose Lukoil Standard mineral motor oil, semi-synthetic motor oil Idemitsu 10W-40 SN/CF and synthetic motor oil Lukoil Genesis Advanced 10W-40 SN/CF.

Important temperature indicators of oils that allow them to compare and determine the temperature range of application are the onset temperatures and critical temperatures of the oxidation processes. Moreover, the critical oxidation temperature was determined by the time the optical density reached values equal to D = 0.05 at each test temperature (figure 2) and the onset of oxidation processes was determined by the optical density after 30 hours of testing (figure 3).
The critical oxidation temperature of the studied motor oil can be determined by taking the logarithm the time of reaching the optical density value $D = 0.05$ at test temperatures of 160, 170, and 180 °C (figure 2). This dependence is described by the following linear equations:

For Idemitsu:
$$ lg t_D = 0.0251(225 - T) $$

For Lukoil Genesis:
$$ lg t_D = 0.0252(222.6 - T) $$

For Lukoil Standard:
$$ lg t_D = 0.0266(217 - T) $$

where 0.0251, 0.0252, 0.0266 are the coefficients characterizing the rate of change of the decimal logarithm of the time of the change in optical density; 225, 222.6, 217 - coefficients characterizing the critical temperature.

The intersection points of these dependences with the temperature axis correspond to the critical oxidation temperature of the studied motor oils, which is: for Lukoil Standard - 217 °C, for Lukoil Genesis - 222.6 °C, for Idemitsu - 225 °C.

The start time of oxidation was determined by the dependence of the optical density on the test temperature after 30 hours of temperature control (figure 3). These dependencies are described by linear equations:

For Idemitsu:
$$ D = 0.0015(T - 160) $$

For Lukoil Genesis:
$$ D = 0.003(T - 158.1) $$

For Lukoil Standard:
$$ D = 0.0035(T - 154.4) $$

where 0.0015, 0.003, 0.0035 are coefficients characterizing the rate of change of optical density and test temperature; 160, 158.1, 154.4 - coefficients characterizing the temperature of the onset of oxidation.

To determine the critical temperature of the conversions occurring in the studied oils, it is necessary to calculate the decimal logarithm of the time to reach the thermo-oxidative stability.
coefficient equal to $P_{TOS} = 0.05$ and construct a graphical dependence of $\log_{10} t_{P_{TOS}}$ on the test temperature (figure 4). These dependencies are described by linear equations:

\[
\begin{align*}
\text{Idemitsu:} & \quad \log_{10} t_{P_{TOS}} = 0.0195(234.3 - T) \\
\text{Lukoil Genesis:} & \quad \log_{10} t_{P_{TOS}} = 0.0121(270.3 - T) \\
\text{Lukoil Standard:} & \quad \log_{10} t_{P_{TOS}} = 0.0253(215 - T)
\end{align*}
\]

The intersection points of these dependences with the temperature axis determine critical temperatures, which are: for Lukoil Standard - 215 °C, for Lukoil Genesis - 270.3 °C, for Idemitsu - 234.3 °C.

Using the above equations, you can determine the decimal logarithm of the time to reach the $P_{TOS}$ coefficient for other temperatures, and the antilogarithm will determine the test time to the value of the coefficient $P_{TOS} = 0.05$.

![Figure 4](image.png)

**Figure 4.** Dependences of the decimal logarithm of the time to reach the coefficient of thermo-oxidative stability of a value equal to $P_{TOS} = 0.05$ ($\log_{10} t_{P_{TOS}}$) on the test temperature of motor oils: 1 - Lukoil Standard; 2 - Lukoil Genesis; 3 - Idemitsu.

To determine the temperature of the beginning of the conversion processes of the test engine oil, it is necessary to build a graphical dependence of the coefficient of thermo-oxidative stability on the test temperature after 30 hours of temperature control (figure 5). These dependencies are described by linear equations:

\[
\begin{align*}
\text{Idemitsu:} & \quad P_{TOS} = 0.0067(T - 157.4) \\
\text{Lukoil Genesis:} & \quad P_{TOS} = 0.0164(T - 145.1) \\
\text{Lukoil Standard:} & \quad P_{TOS} = 0.005(T - 152)
\end{align*}
\]

where 0.0067, 0.0164, 0.005 are the coefficients characterizing the rate of change of the thermo-oxidative stability coefficient; 157.4, 145.1, 152 - coefficients characterizing the temperature of the beginning of the conversion processes in the test oil, taking into account the processes of oxidation and evaporation.
Figure 5. Dependences of the coefficient of thermo-oxidative stability on the temperature of testing of motor oils: 1 - Lukoil Standard; 2 - Lukoil Genesis; 3 - Idemitsu.

According to the data of four tests (points) at which the oil study lasted 32 hours, the indicators of the coefficient of thermo-oxidative stability were established and graphical dependences of the oils Idemitsu (figure 6) and Lukoil Genesis (figure 7) were built. According to the graphical dependencies, it was found that at each test temperature the dependencies are linear and the data obtained experimentally after 32 hours of testing are included in the confidence interval of the linear regression indices obtained from four points for each temperature. During the study, it was experimentally established that 32 hours are enough for the study, which is 82% less than the really spent time, which was 200 hours.

Figure 6. Dependences of the decimal logarithms of the coefficient of thermo-oxidative stability on the decimal logarithm of the time and temperature of testing semi-synthetic Idemitsu 10W-40 SN / CF motor oil: 1 - 160 °C; 2 - 170 °C; 3 - 180 °C.
Figure 7. Dependences of the decimal logarithms of the coefficient of thermo-oxidative stability on the decimal logarithm of the time and temperature of testing synthetic Lukoil Genesis Advanced 10W-40 SN/CF: 1 - 160 °C; 2 - 170 °C; 3 - 180 °C.

The regression analysis data are presented in tables 1 and 2.

Table 1. Regression analysis of experimental data of semi-synthetic motor oil Idemitsu 10W-40 SN / CF.

| Parameter | Test temperature, °C |
|-----------|----------------------|
|           | 160 | 170 | 180 |
| Regression Equations: |       |     |     |
| - for 2 points | 2.19 lg – 0.829 | 2.225 lg – 0.473 | 2.425 lg – 0.596 |
| - for 3 points | 1.86 lg – 0.413 | 2.087 lg – 0.337 | 2.534 lg – 0.703 |
| - for 4 points | 1.82 lg – 0.364 | 2.089 lg – 0.338 | 2.666 lg – 0.842 |
| - for all points | 2.19 lg – 0.829 | 2.086 lg – 0.271 | 2.597 lg – 0.757 |
| Correlation coefficients: |       |     |     |
| - for 2 points | 1 | 1 | 1 |
| - for 3 points | 0.99 | 0.99 | 0.99 |
| - for 4 points | 0.99 | 0.99 | 0.99 |
| - for all points | 0.99 | 0.98 | 0.99 |

Table 2. Regression analysis of experimental data of synthetic motor oil Lukoil Genesis Advanced 10W-40 SN/CF.

| Parameter | Test temperature, °C |
|-----------|----------------------|
|           | 160 | 170 | 180 |
| Regression Equations: |       |     |     |
| - for 2 points | 2.196 lg – 0.623 | 1.904 lg + 0.024 | 1.678 lg + 0.414 |
| - for 3 points | 2.069 lg – 0.498 | 1.952 lg – 0.024 | 1.961 lg + 0.135 |
| - for 4 points | 2.046 lg – 0.473 | 2.042 lg – 0.118 | 2.096 lg – 0.007 |
| - for all points | 2.249 lg – 0.771 | 2.300 lg – 0.430 | 2.411 lg – 0.363 |
| Correlation coefficients: |       |     |     |
| - for 2 points | 1 | 1 | 1 |
| - for 3 points | 0.99 | 0.99 | 0.98 |
| - for 4 points | 0.99 | 0.99 | 0.98 |
| - for all points | 0.99 | 0.99 | 0.98 |

As we can see from figure 6-7 and tables 2 and 3, it is impossible to use only two points for forecasting, since in subsequent tests, linear regression can sharply change its intensity.

When choosing four test results (points) for prediction, the difference between the experimental data and the data obtained as a result of the forecast is minimal and does not exceed 5%. This means that the similarity of linear regressions is approximately 95%, which contributes to further forecasting of future indicators, which helps to reduce the complexity by reducing test time.

3. Conclusions
As a result of the analysis of the obtained data, the forecasting method was experimentally confirmed, which will allow several times to reduce the time of testing aimed at assessing the thermo-oxidative stability of lubricants.

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