Theoretical aspects of assessing the residual engine oil resource

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Abstract. The article reflects issues related to changes in the properties of engine oil during operation. Proposals are considered for creating a methodology for assessing the residual resource of engine oil by the example of changing the kinematic viscosity. The operating conditions of cars vary greatly, which affects the change in the engine oil resource. Automotive manufacturers set the engine oil change interval in kilometers. The actual resource of the engine oil may differ significantly from that recommended by the manufacturer of the equipment and declared by the manufacturer of the oil. The article presents the factors that determine the resource of engine oil and theoretical aspects of assessing the residual resource of engine oil. To assess the residual life of the engine oil, it is proposed to select a diagnostic indicator that comprehensively evaluates the state of the operating oil, assign limit values for the diagnostic indicator, fix the values of the diagnostic indicator during daily maintenance of the car, replace the dependence by which the diagnostic indicator changes with an approximating straight line, determine the coefficients for the approximating direct based on the last and previous values of the diagnostic indicator and operating time, calculate the engine oil operating time to the limit state according to a linear relationship. The results of testing and forecasting the residual resource of engine oil for a motor transport enterprise are presented. Calculations made it possible to establish that the frequency of engine oil change can be increased relative to that adopted at a motor transport company by 28.3%.

1. Introduction
An important reserve for saving material resources during the technical operation of vehicles is the most complete use of the resource of engine oils. The reliability and service life of a car engine directly depends on the quality and condition of engine oil. Car manufacturers set engine oil change intervals in kilometers (miles). The scientific community and specialists of car service enterprises are finding alternative approaches to the appointment of change intervals.

2. Engine oil life and its determining factors
There are several factors that determine the life of an engine oil. A modern car engine operates under extreme conditions that change the properties of the engine oil. Given this, the manufacturer of the equipment recommends regular replacement after a certain mileage with some reservations to consider difficult operating conditions.
In many ways, the resource of engine oil depends on the operating conditions of the car, among which the following should be noted:

- Driving the vehicle over short distances when the engine (and engine oil) does not reach optimum operating temperature and the power unit is running on a rich fuel mixture.
- Long-term operation of the engine in conditions of traffic jams at idle;
- «Sporty» driving style, aggressive driving style;
- Prolonged idle time of the car without movement, when the owner rarely uses the vehicle;
- Use of low-quality consumables (filter elements of the lubrication system, air purification, etc.);
- Low quality of motor fuel;
- Overheating of the engine and engine oil due to excessive loads, etc.

Along with this, the technical condition of the automobile engine and its systems affects the resource of the engine oil: the power supply system, the ignition system (for gasoline engines), the crankcase ventilation, the engine control unit, etc.

Thus, it can be stated that the resource of engine oil depends on a large number of factors that are difficult to consider. Under these conditions, as a general recommendation, you can either change the oil according to its actual state, or reduce the recommended oil change period by one and a half to two times.

3. Theoretical aspects of assessing the residual resource of engine oil

Residual resource of engine oil is the operating time of the lubricant from the current to the limit state. To assess the residual resource of engine oil, you must:

- Choose a diagnostic indicator that comprehensively evaluates the condition of the operating oil;
- Assign limit values for a diagnostic indicator;
- Measure the values of the diagnostic indicator several times with different operating time;
- Determine the mathematical relationship by which the diagnostic indicator changes;
- Determine the coefficients for the selected mathematical relationship;
- Calculate the operating time of the engine oil to the limit state.

The actual resource of the engine oil may differ significantly from that recommended by the manufacturer of the equipment and declared by the manufacturer of the oil.

Scientists and manufacturers of automotive and road construction equipment recommend evaluating the condition of engine oil by the following indicators: kinematic viscosity, flash point in an open crucible, alkaline and acid numbers, water content, content of mechanical impurities, incl. soot, silicon, iron, copper, etc [1, 2, 5, 6]. The dependences of changes in the quality indicators of engine oil are described in sufficient detail in the literature [1, 3, 4, 7, 8].

Under stable operating conditions of the car, it is enough to measure from 2 to 5 values of the diagnostic indicator of engine oil and build a linear or non-linear regression model describing the change in the diagnostic indicator. Instead of a mathematical model of the influence of operational parameters, you can use empirical dependencies described by linear, polynomial, exponential and other dependencies. A large number of diagnostic points allows you to more accurately build the regression equation and predict the residual resource. If the operating conditions of the car change: there is an instability of the quality of the car fuel, several drivers are assigned to the car, the car is operated on different routes and with different loads, then the coefficients of the regression model describing the state of the engine oil must be adjusted.

By increasing the frequency of measurements of the diagnostic indicator, it is possible to more accurately record changes in the properties of engine oil in real time. With an infinite number of discrete measurements, the function of changing the diagnostic parameter of the engine oil will turn into a continuous one. At each point of a continuous function, the trend of its change can be described by a tangent. On a small segment of the engine oil operating time, the tangent function approaches the function itself. Thus, with sufficiently frequent discrete measurements, the function of changing the
diagnostic indicator of engine oil can be replaced with tangents. When the operating conditions of the car change, the intensity of the change in the diagnostic indicator of the engine oil, and, accordingly, the angle of inclination of the tangent will change.

By extending the tangent to the last point of the engine oil diagnostic indicator graph, you can determine the point of its intersection with the boundary line. Replacing the function of changing the diagnostic indicator of its tangent allows you to go to a linear relationship. Evaluation of the linear dependence of the change in the resource of the engine oil seems to be a simpler task compared to the recalculation of the coefficients of the regression model. In this case, the assumption is introduced that the change in the diagnostic indicator will be linear until the limit state of the oil is reached. With a large residual engine oil resource, this assumption will reduce the prediction accuracy. As the properties of the oil approach the limiting state, the prediction accuracy will be increased.

With a low labor intensity of oil analysis (less than 5 man-min.), it is possible to recommend measuring the diagnostic indicator of engine oil during daily car maintenance. With an average daily mileage of 200 km and an engine oil change interval of 10 - 20 thousand km, 50 - 100 measurements will be carried out. During a work shift, the operating conditions of the car can be considered stable. Thus, sudden changes in the properties of the engine oil will be recorded at the end or before the start of the work shift. Information about a change in the properties of engine oil may indicate a violation of operating conditions and correct its residual resource.

The residual resource of the engine oil will be defined as the operating time before the intersection of the straight line approximating the function of changing the diagnostic indicator with its boundary value. The formula for the approximating straight line is:

\[ a(l) = kl + b, \]  

(1)

where \( a(l) \) is the calculated diagnostic indicator of the engine oil;
\( l \) is engine oil operating time, km;
\( k \) and \( b \) are the coefficients of the linear equation.

The slope \( k \) is equivalent to the rate of change in oil properties and is calculated as the ratio of the change in the value of the diagnostic indicator to the change in operating time:

\[ k = \frac{\alpha_l - \alpha_{l-1}}{l_l - l_{l-1}}, \]  

(2)

where \( \alpha_l \) is the value of the diagnostic indicator at the current time;
\( l_l \) is operating time at the current time
\( \alpha_{l-1} \) is value of the diagnostic indicator at the previous measurement;
\( l_{l-1} \) is operating time during the previous measurement

The free term is calculated by substituting the current values of the diagnostic indicator and operating time into the equation of the straight line:

\[ b = a_l - kl_l. \]  

(3)

To determine the residual life of the engine oil \( l_0 \), the operating time must be expressed from formula (1). The current values of the coefficients \( k \) from the formula (2) and \( b \) from the formula (3) are substituted into the formula (1). The boundary value \( \alpha_{\text{min}} \), is used as the value of the oil diagnostic indicator if the diagnostic indicator decreases \( (k < 0) \) and \( \alpha_{\text{max}} \) if the diagnostic indicator increases \( (k > 0) \) during maintenance:

\[ l_0 = \begin{cases} 
\frac{a_{\text{min}} - b}{k}, & \text{when } k < 0 \\
\frac{a_{\text{max}} - b}{k}, & \text{when } k > 0 
\end{cases} \]  

(4)

If it is known that the change in the diagnostic oil quality indicator is monotonous, then one equation and one boundary value of the diagnostic oil quality indicator can be limited.
4. Example of predicting the residual life of engine oil

Let us consider the application of linear extrapolation by the example of changing the kinematic viscosity of engine oil. The kinematic viscosity of an engine oil varies in terms of operating time under the influence of various factors. The nature of the change in viscosity is random. To predict the residual life, the values of the kinematic viscosity by operating time were recorded on a Scania P114GA4x2NA340 vehicle. During the test period, 78 measurements of the kinematic viscosity of Mobil Delvac MX Extra 10W-40 engine oil were processed (Fig. 1).

![Sample viscosity 10W-40](image)

After maintenance for 8 thousand km, the kinematic viscosity of the engine oil decreased from 15.1 mm²/s to 14.0 mm²/s. Then the change in viscosity stopped, and after 10 thousand km of oil production, a slight thickening of the oil began to occur. With the service interval of 60 thousand km adopted at the enterprise, it was proposed to increase the operating period until the operating time, at which the kinematic viscosity of the oil at 100°C would go beyond the SAE 40 viscosity class. At the same time, in accordance with the proposed theoretical aspects, the residual resource of the engine oil was predicted (Table 1). The results of tests and predictions of the residual resource of the engine oil showed the need to replace it with operating time of 77 thousand km.

| Oil production, thousand km | 0 | 2 | 5 | 8 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 73 | 76 | 77 |
|-----------------------------|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Residual resource, thousand km | 10 | 14 | 23 | 72 | 70 | 65 | 60 | 50 | 40 | 30 | 20 | 10 |  5 | 1  |  0 |
| Kinematic viscosity, mm²/s | 15.1| 14.5| 14.2| 14.0| 14.0| 14.1| 14.15| 14.3| 14.4| 14.5| 14.7| 15.4| 15.5| 16.1| 16.3|

**Figure 1.** Change in engine oil viscosity by operating time

**Table 1.** An example of predicting the residual resource of engine oil
When predicting the resource of engine oil by kinematic viscosity, it was possible to observe erroneous values of the forecast up to operating time of 8 thousand km. If the tendency of viscosity changes at the beginning of the experiment persisted, the prediction would be correct. However, the nature of the change in kinematic viscosity has changed. According to the calculation according to the proposed formula, the residual resource of the engine oil with operating time of 8 ... 10 thousand km tends to infinity. After operating 50 ... 55 thousand km, the rate of change in viscosity began to grow. After operating 70 thousand km, the predicted residual resource began to decrease. The deviation of the real resource of the engine oil from the predicted one was 3.75%. At the same time, the increase in the resource of the engine oil in comparison with that adopted at the motor transport enterprise was 28.3%.

5. Conclusion

Based on the results of the study, assessing the residual resource of engine oil, it was proposed:

- use the viscosity of engine oil as a diagnostic indicator that comprehensively evaluates the condition of the oil;
- assign viscosity limit values in accordance with the SAE J300 viscosity grade limit values;
- fix the values of the diagnostic indicator during daily maintenance of the vehicle;
- replace the dependence according to which the diagnostic indicator changes with an approximating straight line;
- determine the coefficients for the approximating straight line based on the last and previous values of the diagnostic indicator and operating time;
- calculate the operating time of engine oil to the limit state according to a linear relationship.

The advantages of this method for assessing the residual resource of engine oil are:

- no need to build complex mathematical models of changes in the diagnostic indicator;
- the possibility of using the characteristics of engine oil as diagnostic indicators, the change in which by operating time has been little studied;
- quick correction of the values of the residual resource of the engine oil when operating conditions change.

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