Complex Impact of Multifunctional Additives on Operational Parameters of Engine Oils

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Abstract. The powertrain is the most important and commonly the most expensive component of a vehicle. The useful life of machinery is normally determined by the operating lives of its powertrain and engine. Therefore, there are high requirements for power train reliability and longevity. This article considers the key engine reliability improvement methods, as well as the key modern development concepts for the internal combustion engine. Based on those, the authors justify the use of organic-synthesis multifunctional compounds as engine oil additives.

To get a comprehensive assessment of the impacts of additives on the performance properties of engine oils, the authors developed a testing program. They described the tribological tests performed to determine the anti-corrosion properties, ash content, environmental parameters, and thermal oxidation stability. The article presents the results of these tests reflecting the efficiency of the developed additive. The article is summed up with conclusions.

1. Introduction

Today, almost all industrial sectors require that vehicle powertrain reliability and longevity shall increase. At the same time, the actual operating life of vehicles may increase standard limits by 1.2-1.5 times due to the economic difficulties and the increase in the prices for new machines. Thus, the importance of routine activities and works aiming to prolong the operating life of machines is increasing [1].

Generally, the useful life of a machine can be equaled to the operating life of the powertrain, i.e. the period before it requires major repairs. Thus, improving the reliability of the powertrain and the engine is the key method for the improvement of the reliability of the entire machine [2-4].

Engine reliability is selected during the design stage, facilitated during production, and implemented through rational operation procedures [5]. High engine reliability can significantly reduce the maintenance and downtime costs associated with machinery [6].

Powertrain reliability is determined by its fault-free operation, longevity (normally expressed in service hours), serviceability, and the persistence of the entire machine, as well as its parts and components [7-9].

High reliability of a powertrain can be achieved through the following methods:

1. Improving the fault-free operation of the engine by making its operating life equal or divisible by the operating life of a basic component (e.g. the cylinder block) with greater reliability [10].

2. Increasing the interval before the first major repair through the increase in the operating life of the limiting component [11].
3. Increasing the interval between major repairs and the reduction of repairs costs via the use of advanced restorative and in-place repair methods and the improvement of spare part quality [12-14].

4. Reducing the labor inputs required for maintenance operations and increasing the serviceability via relevant design and engineering activities [15, 16].

Engine reliability is largely determined by the operating conditions, the operational mode, the quality of lubricants and fuel, the presence of abrasive particles in tribocouplings, and lacquer and varnish formation on components. Therefore, to prevent failures, it is necessary to improve the operating conditions for the components [17, 18].

In addition to the above, there are several key ICE development trends today [19]:
1. Increasing the engine power-to-weight ratio and efficiency.
2. Complying with constantly increasing environmental requirements on harmful emissions.
3. Reducing the maintenance and operation costs.
4. Reducing the production and scrapping costs.

The first three of the problems identified can be solved in various ways, e.g. by alternating the powertrain design or using innovative materials [20]. However, such solutions are costly and can only be applied to the machines produced after the solutions in question are deployed. This article focuses on other methods.

It is possible to achieve some progress on the first three problems via the following method: improving power conversion and transmission processes through loss reduction, improving lubrication to reduce power inputs, and using some modified operational materials [21-24].

In this article, engine reliability is improved by using modified lubricants taking into account the restrictions applied.

2. Research methods, equipment, and materials

In this article, we studied two types of lubricating oils. Sample 1 is commercial synthetic engine oil. Sample 2 is the same oil complemented with a multifunctional additive to the proportion of 10%. This additive is a product of the organic synthesis of boric acid, carbon acids, and ethanolamines, making up ethanolamide borate of carbon acids (EBCA).

There are many parameters that can be used to assess the efficiency of engine oils and their additives. In this research, we performed the following tests to get a comprehensive assessment of engine oil parameters:
1. Tribological tests and friction coefficient calculation.
2. Studying the anti-corrosion properties.
3. Measuring ash content
4. Calculating environmental parameters.
5. Studying the thermal oxidation stability (TOS).

The tribological tests were carried out on an II-5018 friction test machine using the Pad-Roller method with the pressing force of 1,000 N for 20 minutes (until stable friction torque values were obtained). After that, we measured the friction torque and used it to determine the friction coefficient. Figure 1 shows the overview of the friction pair. Figure 2 shows the friction pair installed in the test machine.
The anti-corrosion properties were calculated according to GOST 9.054 method 1, under high temperature and humidity with regular moisture condensation on the surfaces of the study objects. For this test, we used 50×50 mm 3-mm thick steel plates prepared according to the mentioned standard. They were covered in the compounds in question and put into a desiccator, the desiccator was put into a heating block which heated up to 80°C every day. The tests were carried out for 4 months. We used the changes in the weight of the plates after the test as the corrosion indicators (the gravimetric method).

The ash content was measured according to GOST 1461-75. The samples were placed in a crucible and set on fire. The remaining substance was baked in a furnace until a constant weight was obtained.

We used the CO2 emission as the environmental friendliness indicator. The test was carried out using a FROUDE CD-60 specialized roll-over testing unit. We studies how the environmental friendliness parameters of VAZ 21126 changed after we added 10% of EBCA into the engine oil. The tests were carried out according to the TRCU, UN Regulations No. 83-06,-07, 101-01,103, FTP-75 (USA), GTP 15. The testing unit is shown in Figure 3.

Figure 1. Overview of the Pad-Roller friction pair.

Figure 2. The friction pair selected for the tests.
To calculate the TOS and obtain some more tangible results, we used mineral oil because synthetic oils have higher TOS. We took two samples of commercial mineral engine oil and added 10% of EBCA to one of them. TOS tests were carried out as follows: The oils were heated in a closed container at 180ºС over a copper catalyst for 15 hours. We used the photometric oil contamination coefficient. This parameter characterizes the accumulation of slightly soluble oxidation products in the oil. The photometric contamination coefficient was carried out following GOST 24943-81.

3. Results and discussion

The results of measurements are shown in Table 1. Based on the data provided, we can make some conclusions about the efficiency of EBCA as engine oil additives. Yet the more detailed analysis and visualization of the results require the normalization and assessment of the available data.

### Table 1. Engine oil testing results.

|                               | Engine oil without additives | Engine oil + 10% EBCA |
|-------------------------------|------------------------------|------------------------|
| Friction coefficient          | 0.24                         | 0.19                   |
| Losses due to corrosion per test, g/m² | 9.9                          | 5.6                    |
| Ash content, %                | 0.85                         | 1.09                   |
| Normalized CO₂ emissions, g/km | 6.4                          | 6.04                   |
| Photometric contamination coefficient | 144.5                      | 134.7                  |

In this case, common normalization methods cannot be used because for the minimax linear conversion (as well as other standard transformations) we can only get 0 and 1. Thus, we will assess parameters against each other. To do this, we transform each of the lines as follows: first, we get the reciprocal values for each of the parameters (see Equation 1), and then we divide the obtained value by the maximum value in the line (see Equation 2). As a result, we get a set of non-dimensional indicators characterizing the proportions of various parameters rather than their numerical values.

\[
X'_i = \frac{1}{X_i} \\
\bar{X}_i = \frac{X'_i}{X_{max}} \\
\]

(1)

(2)
where \( X_i \) is the initial parameter value, \( X_i' \) is the reciprocal parameter value, and \( \bar{X}_i \) is the final relative value.

Thus, the best value in terms of engine operation parameters will be the highest and equal to 1. The minimum value is calculated from this value. The data are shown in Table 2. To perform a comprehensive assessment and compare the properties of the lubricants in question, we organized the data in a radar chart shown in Figure 1. This data visualization method helps compare several different properties of study objects at once.

| Friction reduction | Engine oil without additives | Engine oil + 10% EBCA |
|--------------------|------------------------------|------------------------|
| Atmospheric corrosion protection | 0.79 | 1 |
| Varnish formation reduction | 0.57 | 1 |
| Atmospheric emissions reduction | 1 | 0.78 |
| Thermal oxidation stability | 0.94 | 1 |

Table 2. Comparative data.

![Radar chart showing lubricant parameter comparison](image)

The data presented show that EBCA can be efficient in improving the operational properties of engine oils. Adding 10% EBCA can reduce friction by 20%, corrosion-related losses by 45%, CO\(_2\) emissions by 6%, and the photometric contamination coefficient by 7%.

We must note that while EBCA can reduce friction and harmful emissions, improve the corrosion resistance of steel parts, and increase the TOS, they also increase the ash content, although this parameter remains within the limits.
4. Conclusions
Based on the results of the tests performed, we may conclude that:
1. Changing lubricant composition has a complex and comprehensive impact on the entire range of the operating properties of the compound.
2. It is possible to improve the operational parameters of a vehicle powertrain without changing its design parameters.
3. The modification of operational materials is one of the efficient ways to improve the operational parameters.
4. EBCA are efficient for the improvement of the operational parameters and reliability of machines.

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