No. 128/23, 7–20
ISSN 2657-6988 (online)
ISSN 2657-5841 (printed)
DOI: 10.26408/128.01

Submitted: 10.01.2023
Accepted: 09.05.2023
Published: 29.12.2023

THE IMPACT OF THE ADDITION OF EFFECTIVE MICROORGANISMS ON SELECTED PARAMETERS OF ENGINE OIL

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Abstract: This article presents the problem of microbial contamination in petroleum products and describes in detail the presence of microorganisms and the methods currently used to combat microorganisms in lubricating oil. Effective microorganisms have also been characterised in terms of composition and development conditions. The main part of the article presents the effect of the ecological additive on selected parameters of engine oil. From the preliminary results obtained, it is to be concluded that these additives can be added instead of, for example, harmful biocides. Effective microorganisms have a positive effect on the properties of both new and used oil. Therefore, it is justified to conduct further studies for other oil parameters and for different amounts of this ecological additive.

Keywords: engine oil, microbial contamination, oil properties, effective microorganisms.

1. INTRODUCTION

Currently, due to the protection of the natural environment, great importance is attached to the development of alternative drives, especially with the use of electricity (battery and hydrogen vehicles with the use of fuel cells). Electric vehicles will play a major role in the transition to sustainable transport, enabling decarbonisation and increasing the profitability of transport [Scania 2019, Nieuwenhuis, Cipcigan and Berkem Sonder 2020]. Nevertheless, it still makes sense to work on the development of internal combustion engines, as these will be present on the roads for many years, especially for transporting goods by road or sea.

For this reason, research is still being conducted on reducing the emission of harmful compounds into the atmosphere from exhaust gases, and solutions aimed at reducing fuel consumption are being sought. Other problems are related to lubricating oil operating in particularly harsh conditions. Due to the oil rapidly losing appropriate parameters, frequent oil changes are required. This has an impact on economic issues and, above all, on the environment. Used oil is a hazardous waste and requires special attention after its disposal from a reciprocating engine [Katiyar and Husain 2010; Idzior and Wichtowska 2016].

One of the problems with an oil ageing too early is the presence of microbes. Good quality petroleum products must be light and transparent, while the growth of microorganisms can often contribute to its turbidity and darkening. Microbial contamination is caused by a number of factors, including changes in the source and quality of petroleum products, the increasing use of fuel and oil additives that can provide compounds for microbial growth, and changes in the management and storage of these products. The bio-additives introduced in recent years also contribute to the development of microbiological life in reservoirs. This results in the formation of green-brown gelatinous masses in petroleum products. This "jelly" is a kind of biological sludge made up of long fibrous chains containing both living and dead cells [Gaylardeet, Bento and Kelley 1999; Zhang et al. 2021].

Nowadays, biocides are most often used to combat microorganisms in petroleum products, i.e. synthetic or natural compounds to combat harmful organisms. Biocides are pesticides used, inter alia, to combat or limit the growth of microorganisms in petroleum products. Biocides should have a broad spectrum of activity against various groups of microorganisms, dissolve in the water and organic phase, be effective at low concentrations and efficient in use, have anti-corrosive properties and compatibility with various petroleum systems or should not decompose at the operating temperature of lubricants. Due to the fact that biocides are not environmentally friendly, alternatives are being sought. One of them may be effective microorganisms classified as ecological products [Enzien 2011; Turkiewicz, Brzeszcz and Kapusta 2013].

The composition of different strains of aerobic and anaerobic microorganisms, incl. Lactic bacteria, yeasts, photosynthetic bacteria, molds and actinomycetes, was developed by prof. Teruo Higa from Japan. EM technology is based solely on natural processes. They are an extremely effective, living substance that acts in a different way from antibiotics and chemicals. In Asia and many poor countries, the introduction of this technology has seen an increase in yields, hence the increase in the standard of living. Effective microorganisms are most often used in agriculture, especially ecological, for soil fertilisation, in animal husbandry and in the processing of organic waste. In Japan, Germany, Australia and Kenya, this technology has been used in the processes of water treatment and treatment of domestic, municipal and industrial wastewater as well as the treatment of contaminated water reservoirs [Higa 2003; Schicht 2008; Kolasa-Więcek 2010].

This article presents a study of the influence of the use of effective microorganisms in new and used oil.

2. CONTAMINATION OF LUBRICATING OIL WITH WATER

Water in oil comes in three forms: dissolved water, emulsified water, and free water. The point at which the oil cannot absorb more dissolved water is called the oil saturation point. If more water gets into the oil, the excess water will appear as separated water or an emulsion. Generally, if the saturation point is exceeded, the oil begins to resemble a milky substance, which confirms the phenomenon obtained after mixing the oil with certain amounts and types of effective microorganisms added. How much water the oil can hold depends greatly on the quality of the base oil, additive package, operating temperatures and pressure. For example, a highly refined oil with few additives will withstand a small amount of water before being saturated, around 100 ppm at 21 ^{o}C. On the other hand, an ester-based oil can withstand 3000 ppm of water at 21 ^{o}C and above [Niewczas, Wrona and Wrona 2010], probably with some decomposition or a chemical reaction.

2.1. Water pollution effect

Water is one of the oil contaminants that pose a great threat to the lubricated devices. Therefore, in terms of its harmfulness, it is the second oil-degrading factor after particulate matter.

Water occurs in the form of:

- an emulsified substance, as a stable emulsion causing its turbidity;
- in a free state, with water clearly separated from the oil;
- water molecules not visible to the naked eye.

The saturation and form of water in the oil depend mainly on the amount of water, operating temperature, type of base oil, as well as the degree of ageing and additives.

The source of water in oil systems may be caused by: leaky cooling systems, residue after cleaning or device evaporation, penetration through piston rods or condensation. It depends on the ambient conditions and air humidity as well as absorption of moisture from the environment.

The presence of water in oil systems deteriorates the rheological properties of the working fluid used, reducing its lubricating and insulating abilities. Water in oil reduces the possibility of bearing loads transferring, accelerates the processes of oil oxidation, rinses out improvers, increases the amount of deposits and causes corrosion. Accelerated wear on metal surfaces may be present even when the water is completely dissolved in the oil.

Water contributes to changes in the oil, both physical and chemical, causing the formation of acids, deposits and sludge. Moreover, it increases the viscosity of the oil and radically lowers its electrical insulating properties.

One method of removing water from the oil is centrifugation, which separates contaminants from the oil using centrifugal force. For this purpose, oil centrifuges are used.

When the removal of free water from the oil is insufficient, vacuum dewatering can be used. Unlike other water removal methods, vacuum dehydration removes the separated water and the water bound in the oil from the oil system. Vacuum dehydration removes 100% of free and emulsified water and up to 90% of dissolved water. In addition, it also removes 100% of adsorbed gases and up to 80% of gases dissolved in oil [Sander 2009; Dealtry et al. 2018].

Figure 1 shows the dissolving capacity of water in oil as a function of temperature, i.e. a typical oil saturation curve [Ecol 2022].

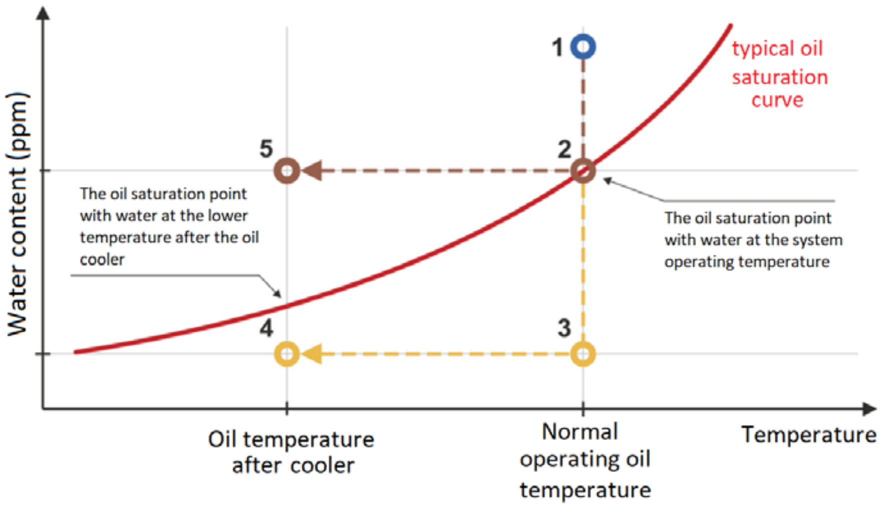

Fig. 1. The ability to dissolve water in oil depending on the temperature (saturation curve)

Source: [Ecol 2022].

Contamination in the oil and hydraulic systems of machines has a destructive effect on the quality and life of the oil, but most importantly, it negatively affects the condition of the device itself. The presence of contamination may disturb the proper functioning of the machine and even lead to serious failure. Contaminants in the oil come in various forms: solid, liquid or gas. Their presence may result from the entry of pollutants into the system from the outside, precipitation of oil ageing/decomposition products, as well as that resulting from the cooperation of machine elements or corrosion [Du, Wu and Gong 2017; Afzal et al. 2019].

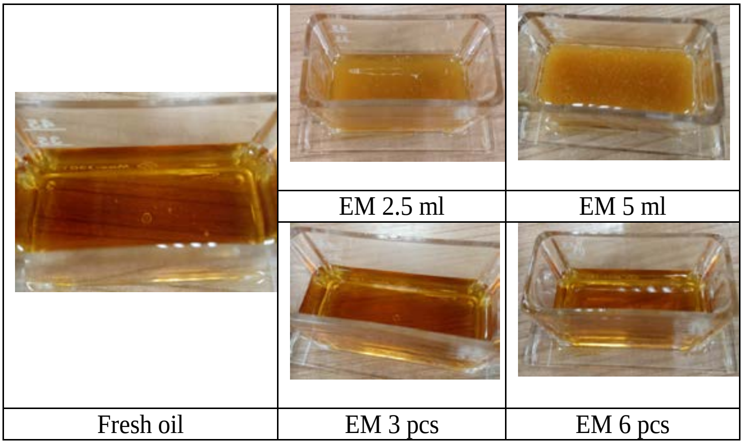

Fig. 2. Colouring of fresh oil, with the addition of effective microorganisms in liquid form and ceramic tubes

Figure 2 shows the colour of the samples, which indicates that after adding microorganisms in a liquid form to the new oil, they became an oil-water emulsion, and in this form they are not suitable for use as a lubricating oil.

3. MATERIALS AND METHODS

Two types of oils were used in the tests in order to compare the effectiveness of the ecological additive, both in new and used oil.

3.1. Materials used in the research

For the research, 5W30 synthetic oil was used. This oil is synthetic and has emission system protection formula. This lubricant perfectly lubricates engine parts, while protecting it against deposits of solid contamination, sludge and other harmful impurities that cause it to wear faster. The oil described is characterised by its optimal viscosity from -30 ^{o}C and its fluidity at -35 ^{o}C [Substech 2022]. The used oil was the same type as the new oil.

The oil had a mileage of. approx. 10 000 km, and it came from a car internal combustion engine. The car covered 75% of the routes in urban traffic, while the rest came form non-urban routes and expressways.

Before starting the research, effective microorganisms were added to the oil about four weeks earlier. The effective microorganisms of the commercial form were shown in Figure 3.

Fig. 3. The commercial form of effective microorganisms in liquid form and ceramic tubes

Source: [Ecoshop 2022, Falaem 2022].

The effective microorganism product manufactured by Greenland Technologia used in the research has the following composition: water: 94%; Effective Microorganisms® (yeast, photosynthetic bacteria, saprophytic bacteria, lactic acid bacteria, actinomycetes and fungi): 3%; molasses: 3%.

Effective microorganisms in the form of ceramic tubes are a special type of fermented clay, which mature in natural conditions for several months. Next it is fired at high temperatures (1200–1300°C) in anaerobic conditions. They include compositions of beneficial microorganisms, sugar cane molasses, and restructured water. Ceramic tubing consists of materials such as as clay, silica stone, and feldspar. The shapes of the fired elements depend on their future use and the content of effective microorganisms is 3% in each ceramic tube.

3.2. Research methodology

Viscosity is the most important parameter of lubricants and largely reflects the quality of the oil. It is a physical quantity that describes the behaviour of a liquid at a given temperature [Intrucks 2019].

In practice, two different physical quantities are used: dynamic viscosity and kinematic viscosity. In the field of engine oils used in industry, the latter is most often used, which also expresses the density of the liquid (it is the quotient of the dynamic viscosity and density) [Flottweg 2022]. For this reason, the article presents the dependence of kinematic viscosity [Wolak and Zając 2017] on temperature for used and new oil in comparison with the addition of effective microorganisms. Additionally, the course of the density for new and used oil is also shown in the graph.

In order to determine the kinematic viscosity of new and used oil with and without any additives, the oil density was tested with the Oscillating Density Meter DA640. This device (Fig. 4) enables a quick, accurate measurement of this physical quantity using the phenomenon of changes in the vibration frequency of the measuring sensor depending on the changes in the density of its environment (the tested fluid). Then, the value of the kinematic viscosity was obtained from the calculation of the ratio of the previously measured dynamic viscosity to the oil density. The selected parameters of the densimeter are shown in Table 1.

Fig. 4. Oscillating density meter DA640 used in oil tests

Source: [MEF GMU Laboratory2016].

Table 1. Selected parameters for the oscillating density meter DA640

No.	Parameters	Value
1	Density measurement range	0–3 g/cm^3
2	Temperature range	0–93 ^{o}C
3	Accuracy of temperature measurement	0.05 ^{o}C
4	Accuracy of density measurement	+/- 1x10^{-4} g/cm^3
5	Measurement repeatability	1x10^{-5} g/cm^3

Source: [Ekma 2022].

New and used oils with liquid and ceramic effective microorganisms were used for the research. 2.5 mL and 5 mL of additives per 100 mL of oil, and three or six pieces of ceramic tube with diameters of 9 mm and heights of 11 mm were added to the samples.

In order to obtain indicators of the density of the oil [Kyoto Electronics Manufacturing 2022], at least 1 mL of the sample should be given to the device.

The measurement of the density of one sample should take a minimum of 20 seconds, although this may vary depending on samples and ambient conditions etc. Once oscillation frequency becomes stable, measurement comes to an end and the result (density of sample) will be shown.

4. RESULTS AND DISCUSSION

The test results are shown in the form of charts in Figures 5 and 6. These graphs present the impact of each of the additives on the kinematic viscosity of the engine oil samples. Each sample of pure oil and oil with additives was tested three times, at a temperature of 2 °C to 63 °C, because this was the maximum temperature to which the heater cooperating with the viscometer could heat the oil.

Next, using a programme based on ASTM D341 interpolation [Anton Paar 2022], the kinematic viscosity up to 100 °C was determined. So that changes in viscosity in a wider temperature range can be observed, the viscosity is presented in the tables describing the parameters of the oil at 40 °C and 100 °C [Intrucks 2019]. For this reason, in the article, even within this temperature range, the kinematic viscosity courses will be presented. In this article, the average result for each case is demonstrated. Additionally, the density curve for new oil in the same range is also shown. This density made it possible to determine the kinematic viscosity.

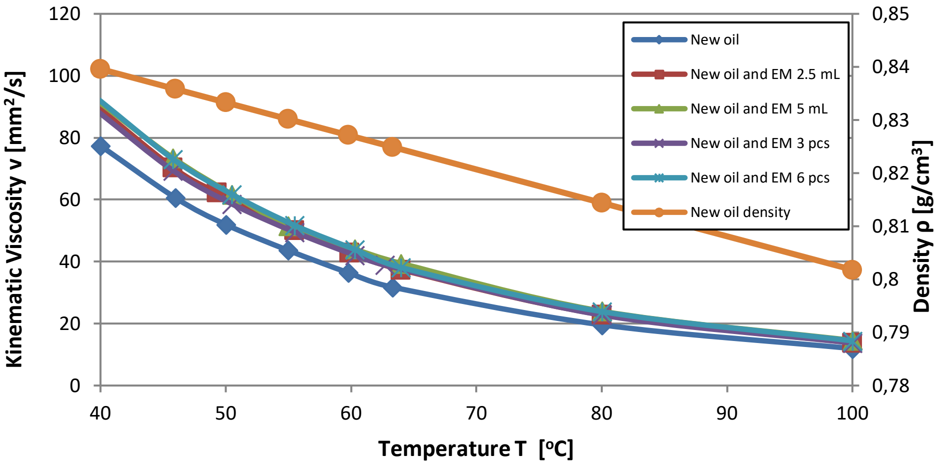

Fig. 5. Comparison of kinematic viscosity of new oil with the addition of effective microorganisms in liquid and ceramic form. New oil density course

Additionally, in order to obtain better clarity, the results obtained are also presented in Table 2.

Table 2. Comparison of kinematic viscosity of oil without and with various additives

	Oil kinematic viscosity at 40 °C [mm²/s]	**Oil kinematic viscosity at 100 °C [mm²/s]**
Fresh oil	77.42	11.95
Fresh oil and EM 2.5 mL	89.56	13.78
Fresh oil and EM 5 mL	91.46	15.56
Fresh oil with EM 3 pcs	88.13	13.71
Fresh oil with EM 6 pcs	92.17	14.43
Used oil	70.52	10.75
Used oil and EM 2.5 mL	71.09	11.52
Used oil and EM 5 mL	91.92	14.39
Used oil with EM 3 pcs	87.08	13.40
Used oil with EM 6 pcs	77.42	11.95

When analysing the results obtained, it can be observed in Figure 5 that the kinematic viscosity of fresh oil with no EMs is 77.42 mm^2/s at 40 °C and 11.95 mm^2/s at 100 °C. The addition of 2.5 mL and 3 pieces of microorganisms to the oil shows a similar course.

However, for microorganisms in liquid form, the viscosity value is higher in the lower temperature range compared to the course with the addition of ceramic tubes. Effective microorganisms cause a unconsiderable increase in the kinematic viscosity in the oil compared to oil without such an additive and is equal for 2.5 mL of liquid effective microorganisms (89.56 mm^2/s at 40 °C), and for 3 pieces of ceramic tubes (88.13 mm^2/s at 40 °C). At a temperature of 100 °C, the results are 13.78 mm^2/s and 13.71 mm^2/s respectively.

As for the outcomes obtained for 5 mL and 6 tubes of microorganisms, the waveforms are very similar to each other, while the greater number of effective microorganisms results in an even higher value of kinematic viscosity than that obtained for pure new oil. The value of the determined viscosity for the additive in the amount of 5 mL and 6 pieces of ceramic tubes at 40 °C is 91.46 mm^2/s and 92.17 mm^2/s respectively, while for 100 °C it is 15.56 mm^2/s and 14.43 mm^2 /s.

Moreover, the graph shows that the kinematic viscosity most similar to that of pure oil was obtained with a smaller amount of microorganisms added, especially in the form of ceramic tubes. Therefore the behaviour of the oil with a smaller number of ceramic tubes should be checked in further tests.

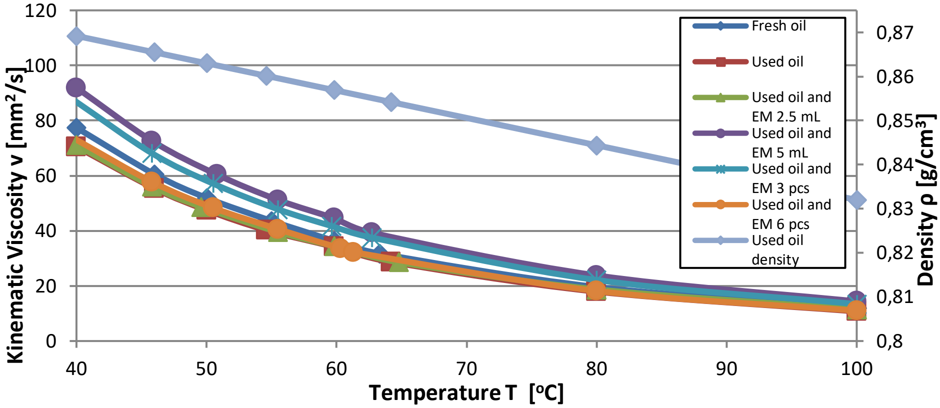

Fig. 6. Comparison of kinematic viscosity of used and used oil with the addition of effective microorganisms in liquid and ceramic form. Used oil density course

In Figure 6, we can see changes in kinematic viscosity from the temperature for used and used oil samples, with the addition of effective microorganisms in liquid form (2.5 and 5 mL) and in the form of ceramic tubes (3 pieces and 6 pieces). The density curve for used oil was also shown in order to better visualise the results obtained. This density made it possible to determine the kinematic density. The viscosity courses are presented in the temperature range from 40–100 °C. In order to illustrate the obtained results better, the viscosity curve for the new oil has been added. The kinematic viscosity value of used oil with no effective microorganisms is 70.52 mm^2/s at 40 °C and 10.75 mm^2/s at 100 °C. We also obtained similar values for the addition of EMs amounting to 2.5 mL, which means that this form and the amount of microorganisms did not show any effect on the oil viscosity. Slightly higher values can be seen for oil with six ceramic pipes, but still deviate from the viscosity obtained for new oil (77.42 mm^2/s at 40 °C and 11.95 mm^2/s at 100). The situation is different for the addition of three ceramic tubes and 5 mL of effective microorganisms. The values obtained are higher for both used and new oil without additives. The following results were obtained for the addition of three ceramic tubes: 87.08 mm^2/s at 40 ^oC and 13.40 mm^2/s at 100 ^oC, while for 5 mL of microorganisms, the result was 91.92 mm^2/s at 40 ^oC and 14.39 mm^2/s at 100 ^oC. The results obtained for used oil confirm that effective microorganisms can improve the parameters of used oil, although more promising results are obtained for new oil. The best results were obtained for effective microorganisms in the form of three ceramic tubes. In further tests, it is worth repeating the tests for a smaller number of ceramic tubes.

In order to confirm the results obtained, the article also presents other selected oil parameters, which are presented in Table 3. They show a comparison of the parameters of new and used oil with and without effective microorganisms.

Table 3. Comparison of the parameters of new and used oil with and without effective microorganisms

	Flash Point [^oC]	**Base Number [mgKOH/g]**	**Water Content [%]**
Fresh oil	212.4	3.907	0.096
Used oil	198.8	1.358	0.167
Fresh oil and EM 2.5 mL	200.4	3.606	0.210
Use doil and EM 2.5 mL	202.4	0.937	0.606
Fresh oil and EM 5 mL	199.6	3.444	Above 1
Used oil and EM 5 mL	202.1	0.844	Above 1
Fresh oil with EM 3 pcs	212.5	3.962	0.072
Used oil with EM 3 pcs	197.5	1.250	0.017
Fresh oil with EM 6 pcs	213.5	3.894	0.097
Used oil with EM 6 pcs	198.1	0.749	0.054

Other oil parameters such as flash point, total base number and water content show that effective microorganisms can be added to the oil to improve its properties. The best results were obtained by adding a smaller amount of ceramic tubes to the new oil. Adding microorganisms to used oil does not bring about the same good results as with new oil. For this reason, further tests of new oil with the addition of microorganisms will be carried out, and then such oil will work in a reciprocating engine in conditions similar to real ones. After use, such oil will be tested again for aging and preservation of its properties, because the aim is to extend the intervals for changing the oil to a new one. Further research will also be carried out on the effect of such an additive on the wear of continuously lubricated internal combustion engine components.

5. CONCLUSIONS

The purpose of this paper was to examine the possibilities of using effective microorganisms to improve the parameters of new and used oil. In the longer term, the study aimed to replace the currently used biocides with an environmentally friendly agent that would reduce the progressive microbial degradation in engine oil. Microbiological contamination lowers the performance of the engine oil, so inhibiting this process may extend the intervals between subsequent oil changes.

Due to the fact that kinematic viscosity is a parameter that illustrates the ease of oil flow in the engine after it is warmed up, this parameter is presented in the article in more detail. In order to confirm the obtained results, the article also presents other important parameters such as flash point, total base number or water content.

The article presents the kinematic viscosity of the oil, which was calculated from the previously performed measurements of dynamic viscosity and oil density for new and used oil without addition and with the addition of effective microorganisms.

New oil studies show that the best results are obtained with the addition of a smaller amount of microorganisms (3pcs) and in the form of ceramic tubes. For this additive, no negative effect on other parameters is noticed, while the viscosity is approx. 13% higher compared to that obtained for the new oil. It is confirmed that the addition of 3 effective microorganisms increased the viscosity in the whole range of very similar values to those obtained for the new oil. For both new and used oil, liquid effective microorganisms have a negative effect on the parameters of the oil, due to the fact that the majority of the composition of this additive is water. In most cases, the addition of microorganisms slightly increases the viscosity, but not so much as to have a catastrophic effect on engine components.

This situation occurs every time a cold engine is started. Too low a viscosity is much more dangerous as it causes the oil to drip easily, so does not have a sufficiently high pressure. On the other hand, too high an oil viscosity is not beneficial either as the oil may not reach all components in time and not dissipate heat quickly enough. The obtained results justify further research with the addition of effective microorganisms in the form of ceramic tubes, while their effect should be checked with a smaller amount of additive.

In future research, the effect of additives on the elemental composition of the oil should be checked, and it should also be ascertained whether rheological shear thinning is taking place. Moreover, further research should reveal whether molasses, as one of the main ingredients of effective microorganisms, has a negative effect on the performance of the engine oil and lubricated piston engine parts.

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