Study of the effects of copper undecylate on the tribological properties of refined waste oil

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Abstract. The results of experimental studies of the use of refined spent oil as a base for manufacturing of lubricants with additives in the form of copper undecylate are presented. The effectiveness of cleaning spent oil by baromembran methods has been shown. The introduction of copper undecylate into the refined spent oil can reduce the friction factor by 1.7 times, wear by 28%.

1. Introduction

The effectiveness of the use of lubricants in various tribosystems is determined not only by the characteristics of the base oil, but also by the effectiveness of the functional additives and fillers used in it. In the process of work in the friction units, the oils used are contaminated, oxidized, which leads to deterioration in their performance characteristics and, ultimately, to loss of performance. Therefore, during periodic maintenance of equipment, the oils are replaced with fresh ones. This raises problems associated with the disposal of contaminated and discarded oil. One of the promising ways to improve the efficiency of the use of lubricating oils is their purification and restoration of operational characteristics to the extent required for the effective operation of tribo-coupling. Currently, various schemes for the purification of contaminated oils have been developed, based on the use of both physical and chemical methods [1-9]. Among the variety of currently existing methods of deep purification of oils, the method of baromembrane filtration can be noted. Depending on the pore size of the membranes, both micro- and ultrafiltration can be carried out. The use of various adsorbents and coagulants can improve the cleaning efficiency.

In the future, refined oils can be used as a basis of lubricant composition, adding a complex of functional additives to them, depending on the conditions for further use in tribo-conjugations. Previous studies [10-11] point to the promising use of various liquid crystal compounds and their mixtures as antifriction and anti-wear additives to lubricants.

2. Goals and objectives of the study

The aim of the study is to develop a method for recycling waste oils by purifying them and introducing effective anti-wear and antifriction additives to obtain lubricants.
3. Materials and methods

A mixture of used engine and transmission oils is used as a starting material. They are cleaned in a multi-stage unit. During the cleaning process, waste oils are subjected to coagulation, separation and ultrafiltration using polymer or ceramic membrane filters. This installation allows to reduce the effect of dispersant additives and to separate mechanical impurities, water and oil aging products.

The design of the installation is shown in figure 1. The used engine oil flows from the reservoir with the initial solution 1 into the reactor 3 by gravity. With the help of a metering pump 12, a coagulant is fed into the reactor from the reservoir 2. The reactor is mixing the used engine oil and coagulant for 20 - 30 minutes. To maintain optimal temperature conditions during separation into the reactor, an electric heating device 22 with automatic temperature control is installed.

![Diagram of the installation](image)

**Figure 1.** Proposed installation scheme for a two-stage recovery of used engine oil:
1 - reservoir with original waste oil; 2 - reservoir with coagulant; 3 - reactor; 4 - pump of the first stage of cleaning; 5 - separator; 6 - intermediate tank; 7 - pump of the second cleaning stage; 8 - reservoir for the concentration of asphalt-resinous impurities; 9 - blocks of membrane tubular modules; 10 - tank with purified waste oil; 11, 13, 14, 15, 16, 17, 18, 26 - throttle valves; 12 - dosing pump; 19 - solenoid valve; 20, 21, 28 - manometers; 22 - thermostat; 23 - level sensor; 24 - pressure line of the 1st stage; 25 - bypass hydraulic line; 27 - pressure line of the 2nd stage.

Then the waste oil treated with the coagulant is fed by the gear pump 4 to the separator 5, where pre-treatment takes place for 15 - 20 minutes. Waste engine oil, pre-purified from mechanical impurities, water and partially from asphalt-resinous compounds, enters the intermediate tank 6.
Thus, the first stage of filtration ends.

Further, the resulting solution can be used as a finished product or be subjected to deeper cleaning. For this, the pump 7 supplies the solution to the parallel-series-connected blocks of membrane tubular modules 9.

Technological modes of the separation process, the pressure drop and the flow rate of the solution through the membrane modules are carried out using throttle valves 15, 18, 26. After the separation process, the concentrate enters the tank 8, the filtrate (permeate) is discharged into the storage tank with purified oil 10.

To maintain the required amount of solution in the tank 8, a level sensor 23 is provided. The piping system, shut-off valves and the solenoid valve 19 provide for continuous filling of the tank with the original used engine oil.

The proposed model does not contain complex mechanical systems, which increases its reliability, and the use of pre-treatment in front of the membrane apparatus allows for improved quality of the permeate.

The analysis of the obtained samples of refined oil was carried out in the accredited laboratory "Ivanovo chemical-technical laboratory" of the Northern Railway of the branch of JSC "Russian Railways".

Copper undecylate was added to the purified spent oil to study the possibility of improving tribological characteristics. This compound was selected on the basis of earlier studies [10, 11], where it was shown that copper carboxylates, which are discotic mesogens, under certain conditions in mixtures with lubricants also exhibit liquid crystalline properties, while copper undecylate exhibits them already at room temperature.

The study of tribological characteristics was carried out on an SMT-1 friction machine according to the "stationary ball - rotating roller" scheme [19, 20]. The test roller was lubricated by immersing it in an oil bath. In the process of research, the coefficient of friction, ball wear, and the temperature of the oil in the bath were determined. The load on the samples was 200 N.

4. Results and discussion

Table 1 presents the characteristics of the oil before and after cleaning.

| Indicator name                              | Indicator value |
|---------------------------------------------|-----------------|
| Kinematic viscosity of oil at 313 K, cSt    | 54.84           |
| Kinematic viscosity of oil at 323 K, cSt    | 37.74           |
| Kinematic viscosity of oil at 373 K, cSt    | 9.77            |
| Density, kg·m⁻³                              | 861             |
| Oil purity, %                               | 97.7            |
| The dielectric constant                      | 2.6293          |
| Base number, mg KOH g⁻¹                      | 6.4             |

As can be seen from table 1, the use of ceramic membranes allows deep cleaning of the oil, while most of the additives are removed from the oil. This is evidenced by a decrease in kinematic viscosity by 1.8-2 times, density and base number by 1.6 times. Water and mechanical impurities are completely removed from the oil. However, no significant oil clarification occurs during the cleaning process. The results of determining the coefficient of friction are shown in figure 2.
Figure 2. Results of determining the coefficient of friction.

As can be seen, the introduction of copper undecylate into the oil leads to a 1.7-fold decrease in the friction coefficient.

Thus, copper undecylate can effectively improve the antifriction characteristics of used oil.

To increase the resource and durability of friction pair, it is required to reduce their wear rate.

Improving the antifriction characteristics of the lubricant by introducing mesogenic copper undecylate makes it possible to improve the operating mode of the friction pair and to reduce the wear rate of the friction pair elements.

Figure 3 shows the results of determining the wear of a stationary sample.

Figure 3. The results of determining the wear of a stationary sample.

The addition of copper undecylate to the purified oil leads to a decrease in the wear of the stationary sample (ball) by 28%, which is comparable with the results obtained earlier [10, 11]. At the same time, the increase in oil temperature during the test in both cases was 293 K.
We associate the improvement in the tribological characteristics of the refined oil with the introduction of the carboxylate with the transition of copper undecylate into the mesophase in the friction zone and with its particular orientation on the friction surface.

5. Conclusion

Thus, copper undecylate is a fairly effective antifriction and anti-wear additive to hydrocarbon-based lubricants and its use in the future will increase the resource of tribo-couplings and the durability of the machine as a whole.

This study also shows that waste oils, after cleaning and restoration of tribological properties, can be used as lubricants in various mechanisms, which makes it possible to solve problems with their disposal.

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