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MECHANIZATION

Change of the Structure and Properties of the Tribo-Preparations to Increase the Efficiency of Tractor Engine In-Place Repair

V. V. Ostrikov[a], S. N. Sazonov[a], V. I. Balabanov[b], V. V. Safonov[c], and I. N. Shikhalev[a]

[a]*All-Russia Scientific Research Institute for Use of Machinery and Oil Products in Agriculture, Tambov, 392022 Russia*
[b]*Russian State Agrarian University—Timiryazev Moscow Agricultural Academy, Moscow, 127550 Russia*
[c]*Vavilov Saratov State Agrarian University, Saratov, 410012 Russia*
e-mail: viitinlab8@bk.ru

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Abstract—The structural changes of the ultrafine compounds and removal of impurities and resins from the operating oils are necessary to increase the efficiency of the in-place repair of tractor engines under the action of the repair-recovery compounds, tribo-preparations. It was revealed as a result of the electron microscopy that the tribo-compounds consisting of molybdenum disulfide, cuprum, and phosphorus modifies its chemical composition, which decreases after being exposed to ammonium hydroxide. To neutralize the action of the oxidation products in the operating engine oil, carbonic acid diamide capable of enlarging the resins, asphaltenes, carbenes, and carboide dissolved in the oil is added into the tribo-preparation composition. Adding the structure lubricating composition to operating engine oil enlarges the impurities' particle size from 0.1–0.5 to 10–20 μm, so that they can be easily removed by the centrifuges included into the lubrication system of the combustion engine. According to the results of evaluation of the antiwear properties of the lubricating compositions consisting of the operating oil with the admixture of the unstructured and structured tribo-preparation, the reduction of the wear spot by 50% in favor of the latter is specified. The comparative bench tests of the repair and recovery compounds before and after structuring showed a high recovery effect of the second (structured) composition.

Keywords: agricultural machinery, tribo-preparation, structuring, motor oil, wear, engine

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INTRODUCTION

The efficient use of resources during operation and repair of agricultural machinery is one of the most important tasks of the agroindustrial sector [1]. Recently, the resource-saving in-place methods of repair using the repair and recovery compounds (RRC), tribo-preparations added to the operating oil, has become more and more popular. These developments have not been widely used yet in the agricultural sector due to the known objective and subjective reasons. First is the high cost of the tribo-preparations, sometimes exceeding the expenditures for the traditional repair methods. Second, there are no clear scientific recommendation on use of the tribo-preparations depending on the wear degree of the parts. As experience shows, many tribo-compounds have a relatively high dispersion ability, which predefines trapping of the metal elements of tribo-preparations by the oil purification filters, and, respectively, reduced efficiency of the tribo-preparation effect. A very important and almost not considered component of the efficient recovery of the worn engine parts is the change of properties of the motor oil operating with the tribo-preparation when the oxidation products reducing the recovery effect are accumulated in it. Based on the above-mentioned facts, the problem of tribo-preparations structuring and increasing their operational properties is specified. Scientific substantiation of the processes occurring in the oil under the action of tribo-preparations, search for the possibility to affect the element composition of the tribo-preparation, and exclusion of the negative actions of the oxidation products of the operating oil on the recovery process are necessary. The compounds for recovery of the metal surfaces are various, but the principle of film formation is reduced to the capability of the metal included into the structure of repair and recovery lubricating composition to "sediment" by the uniform layer on the surface with further structuring under the action of the temperature, pressure, etc.

It is known that the liquid structure is characterized by a certain composition implying the presence of associations with a certain location of atoms and molecules in the volume, which are formed and dissociated due to appearing intermolecular bonds compared with the thermal background energy (~10–15 eV) as well as availability of thermal reactions with energy exceeding the intermolecular and interatomic bonds [2–5]. It should be noted that the oil objects will permanently gravitate toward to the tribo-preparation particles and their uniform distribution in the volume will not be achieved in the presence of the objects. In case of partial removal of the tribo-preparation particles from the volume, the conditions of uniform distribution of the oil objects in the volume and formation of the regular structures called "superlattices" are created. The most important factor of formation of the superlattices of different types is suspension dilution, since the tribo-preparation particles are removed from the volume, then the objects of the first, second, etc. order are removed, which ensures formation of the superlattices of different types.

According to the second law of thermodynamics, at ρ, T = const the substances can spontaneously dissolve in some solvent if, as a result of this process, the Gibbs energy of the system decreases, i.e., $\Delta G = (\Delta H - T\Delta S) < 0$. The value ΔH is called an enthalpy factor, and the value $T\Delta S$ is an entropic dissolution factor. While dissolving the liquid and solid substance, the system entropy usually grows ($\Delta S > 0$), since the dissolved substances pass from the more to the less ordered condition. The contribution of the entropic factor facilitating an increase of solubility is evident at the high temperatures, since the multiplier T and absolute value of the product $T\Delta S$ is also high in this case and the decrease of the Gibbs energy grows respectively [6–8]. The change of the enthalpy of dissolution process can be reviewed according to Hess's law as the algebraic sum of the endo- and exothermic contributions of all processes accompanying the solution process. The solution enthalpy increment $\Delta H_{\text{solution}}$ can be represented as the difference of the energy E_{crystal} of the gross energy for destruction of the crystal lattice of the dissolved substance and the energy $E_{\text{solvation}}$ released during solvation of the particles of the dissolved substance by the solvent molecules. That is, the enthalpy change represents the algebraic sum of the enthalpy change $\Delta H_{\text{crystal}}$ as a result of destruction of the crystal lattice and enthalpy change $\Delta H_{\text{solvation}}$ due to solvation by the solvent particles: $\Delta H_{\text{solution}} = \Delta H_{\text{crystal}} + \Delta H_{\text{solvation}}$, where $\Delta H_{\text{solution}}$ is the enthalpy change during solution. In the process of solution of the solid substances with the molecular crystal structure and liquids, the molecular bonds are not very strong, which is why usually $\Delta H_{\text{solvation}} > \Delta H_{\text{crystal}}$. This leads to the fact that the solution is represented as an exothermic process ($\Delta H_{\text{solution}} < 0$).

One of the advantages is the variant of the superlattice on the objects formed of the tribo-preparation particles of the molybdenum disulfide removed from the modules using the specific technology. Due to the area difference of the molybdenum disulfide microobjects, the excessive oil objects gravitating toward the free surfaces of the molybdenum disulfide deposited on the contact "steel" surfaces will remain in the volume. The interaction of the tribo-preparation admixtures with ammonium hydroxide leads to the change of the medium viscosity, turning it from an easy flowing liquid to an easily mobile gel, later added to the operating medium (oil) and uniformly mixed. The efficient mixing and uniform distribution of gel through the whole volume of oil is ensured by the cumulative motion in the flow at the output from the nozzles of the centrifugal oil purifying devices installed in many combustion engines.

METHODS

The researches on changing of the particle size and structure of the tribo-preparation consisting of the powder of brass, molybdenum, and phosphorus in oil were carried out by mixing it with the carbonic acid diamide. The process of change of the metal element structure in oil was analyzed using an EMV-100A electron microscope. The change of the properties of the operating motor oils was made by adding the ammonium hydroxide to the dissolved suspension with further mixing with the operating oil and centrifuging in OPn-89KHA42. Both aggregation of impurities and structural changes of the mixture were studied under a Digital Microscope. The organic components in the oil and their composition with the repair and recovery compounds were estimated using a Fluorat-02 Panorama photometer. The infrared spectral analysis of oil with the additives was conducted with an Iraffiniti-L device. The antiwear properties of the oil structured with the tribo-preparation were defined with 4-ball friction machine and "block—roller" friction machine. The bench tests of the oil with the additive were carried out in a D-240 full-size engine on a KI-4355 bench, operational tests of the developed lubricating composition were carried out under the conditions of the agricultural production in the engines of MTZ-1221 tractors, and physicochemical analysis of the oil properties was carried out according to GOST methods under the conditions of the certified laboratory.

RESULTS AND DISCUSSION

The most well-known tribo-prepartions added to the lubricating materials for the in-place repair of the combustion engines (CE) have the particle size of 1 μm and more. When they are added and interact with the operating oil, the aggregation of the tribo-prepartion elements with the oxidation products and further sedimentation by the purifying devices built into the lubricating system takes place [9]. The most often applied repair and recovery compound is assumed to carry out the researches on structuring of the tribo-preparation, this compound consists of 0.2% mass filler containing the powder of molybdenum, brass, and phosphorus in the ratio 55 : 30 : 15 and 99.8% of the mineral oil [10], The ammonium

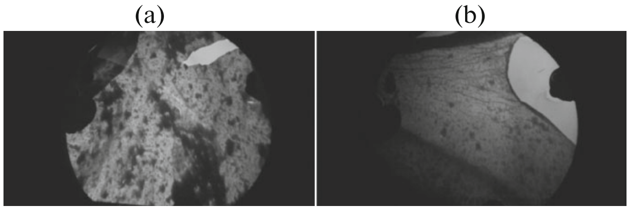

Fig. 1. Appearance of the lubricating composition film: (a) before dilution, (b) after dilution ($C_{magnification}$ = 220000 times).

hydroxide in the concentration of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10% at the temperature 20°C was added to the tribo-compound. The mixture was mixed and the change of the particle size of the powder filler was estimated. It was specified that adding 1 and 2% already leads to the change of the particle size of the tribo-preparation. After settling, the sediment of the blue color forms within 1 hour in the lower part of the suspension. While examining the film of the structured lubricating composition under the electron microscope, its change is specified (Fig. 1).

Further modeling of the tribo-preparation structuring process in the field of the centrifugal forces in the centrifuge OPn-8UKHL42 permitted confirming the fact of structuring of the metal elements of the repair and recovery compound with the decrease of the particle size as the sediment content in the centrifuge glass after their rotation at the frequency of 3000 r/min within 15 minutes made 0.0050, while that during centrifuging of the repair and recovery compound without solution was 0.077; i.e., it reduced more than 15 times.

During analysis of the known researches of the tribo-preparation properties, it has been stated that their addition to the operating lubricating oil hardly affects the oxidation products accumulated in them or negatively affects blocking in some degree the process of recovery of the friction surfaces. The 0.1–0.5% carbon acid diamide was added to the tribo-preparation previously structured by the ammonium hydroxide to neutralize the action of the oil "aging" products. It has been stated as a result of researches that, during mixing the composition with the operating oil (i.e., containing the oxidation products, resins, asphaltenes), the impurity particle sizes (0.1–0.5 μm) enlarge to the sizes (10–20 μm]) easily removed by centrifuging.

The spectral analysis of the oil samples (Fig. 2) showed that the resins and impurities are almost completely removed, the carbon structured is changed, and all dissolved metal components remain in the oil in the process of centrifuging of the oil with the structured tribo-preparation added to it, while the largest part of the metal elements of the repair and recovery compound is settled and almost all resins remain in the oil during its centrifuging with the unstructured tribo-preparation.

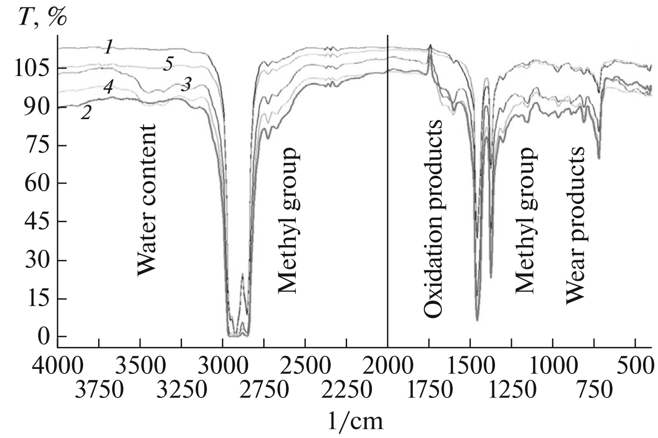

Fig. 2. Comparison of the IR-spectra of the sample of the oils with additives: *1*—commercial oil M-10G_2; *2*—motor oil M-10G_2 operated for 100 meter/hour; *3*—refined operating oil with the additive of 50% solution of the carbon acid diamide and ammonium hydroxide; *4*—refined oil with the additive of the ultrafine preparation consisting of the molybdenum disulfide powder and powder of the brass and phosphorus alloy; *5*—operating oil with the developed lubricating composition.

It was specified according to the results of the evaluation of the antiwear properties of the lubricating compositions consisting of the operating oil with the tribo-preparation additive without its structuring and after structuring procedure that the diameter of the wear spot of the balls in the friction machine on M-10G_2 oil made 0.36 mm, that on the oil with the tribo-preparation made 0.44 mm, and that on the oil with the structured tribo-preparation (after adding and centrifuging procedure) made 0.22 mm; i.e., the oil antiwear properties increased 1.5–2 times.

The tests of the oil with the tribo-preparation on the friction machine "block—roller" showed that the weight loss of the blocks on the operating oil M-10G_2 made 0.0017 kg, that on the same oil after adding the tribo-preparation without its transformation made 0.0012 kg, and that on the oil with the added structured tribo-preparation and passed the procedure of the oxidation products procedure made 0.0005 kg.

The dependence of the friction torque change before setting depending on the load is represented in Fig. 3. It is established that the friction torque under the load has hardly changed in the oil with the structured tribo-preparation additive (line *3*). The oil with the additive of the primary tribo-preparation showed was significantly worse (line *2*), and the load of the compared operating oil (line *1*) had to be reduced to 7 N/m^2 to avoid seizure.

The comparative bench tests of the tribo-preparation were carried out within 200 hours in the D-240 engine. At the first stage of the test, the tribo-preparation was added to the oil operating within 100 hours in the running conditions and the engine was worked to

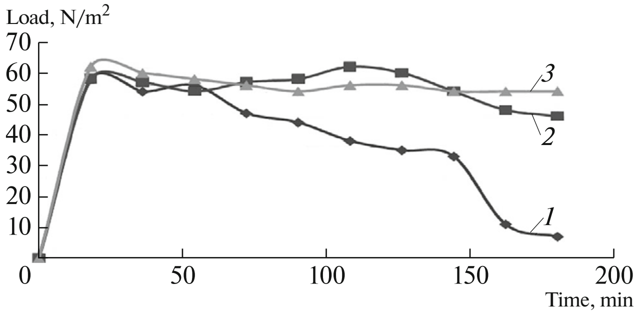

Fig. 3. Dependence of the time moment change before setting depending on the load: *1*—operating oil M-10G_2; *2*—M-10G_2 + 3% cluster; *3*—M-10G_2 + 3% MLC (multipurpose lubricating composition).

200 engine hours. At the second stage, the structured tribo-preparation additive was added to the same oil after 100 engine hours. The results of the micrometreage and weighing of the engine parts before and after tests are given. Analyzing the results of the measurements and weighing of the parts of the main-crank mechanism, we should note that the weight of the main and crank bearings after 200 engine hours on the oil with the primary tribo-preparation increased by 0.0001–0.0002 g, and the bearing mass increased by 0.0004 g on the oil with the structure tribo-preparation. The fact of recovery, "leveling," film formation on the bearing surface is confirmed by the analysis of the friction surfaces under the microscope.

Results of weighing and micrometreage of the parts of engine D-240 before and after the second stage of tests

Before tests		After tests	
bearing, g	crankshaft neck, mm	bearing, g	crankshaft neck, mm
Crank			
98.5896 98.7854	68.23	98.5897 98.7856	68.23
98.5632 98.4587	68.24	98.5635 98.4589	68.24
98.3654 98.4588	68.24	98.3658 98.4590	68.24
98.9124 98.7524	68.23	98.9127 98.7526	68.23
Main			
91.2154 91.1857	75.23	91.2155 91.1858	75.23
91.1354 91.2087	75.22	91.1357 91.2089	75.22
91.1852 91.1691	75.24	91.1853 91.1692	75.24
91.2414 91.1485	75.22	91.2415 91.1486	75.22

The insoluble residue content in the operating oil made 0.7% in the beginning of the tests, while it made 1.2% after adding the primary tribo-preparation and 200 engine hours. During the test of the oil with the added structure tribo-preparation, the insoluble residue content (resins, asphaltenes) decreased to 0.05% after 20 engine hours and the oil changed its color from eight points in the units of the dark-oil products color to five points. Further operation of the engine within 180 hours led to the increase of the soluble residue content in the oil to 0.45%, i.e., almost three times less than in the oil with the tribo-preparation not structured with the ammonium hydroxide and carbon acid diamide. It was also specified that the alkali neutralization number in the oil with the primary tribo-preparation made 1.5 mg KOH/g by the end of the tests, while that with the structured tribo-preparation made 3.8 mg KOH/g; i.e., in the first case, the oil exhausted the reserve of the operational properties, while it had sufficiently high characteristics and useful life for further use in the second case.

As a result of the production tests of the structured tribo-preparation in the normal operation mode of the MTZ-1221 tractors, we received data of change of the combustion engine indices depending on the engine hours. The decrease of the fuel consumption from 25.9 to 25.2 L/h is specified after the tests of the primary tribo-preparation and from 26.5 to 24.1 after the tests of the structured tribo-preparation within 200 hours. In the first case, the compression in the cylinders increased by 5–7%, while compression increased by more than by 15% in the second case. According to the results of the physicochemical analysis of the oil, the increase of its useful life by 40–50% was stated.

It is possible to make a conclusion based on the results that the change of the structure and properties of the tribo-preparation permits significantly increasing the efficiency of its use and prolong the oil change period and service life of the worn agricultural machinery.

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