Research of the parameters of boundary friction of tribosystems in the introduction of surface-modified Al-samples

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Abstract. In this work, the influence of the structure of the adsorption layer of the modified aluminum dispersed powder on the thickness of the boundary layer of the tribosystem with lubrication in the form of oil I-20 with the addition of surface-modified samples was studied. The thickness of the lubricating layer (according to Petrov formula), the value characterizing the antifriction properties under boundary friction conditions, was calculated. The data on the effect of adsorption of various quaternary ammonium compounds on the boundary layer are important for understanding the interaction of these additives with oil components and their ability to reduce friction in the system.

1. Introduction
The main causes of failure of transmissions of equipment and their control mechanisms are the wear of workers, the appearance of unacceptable gaps, etc. In order to ensure their smooth operation, it is necessary to create a stable oil film on the friction surface, which is achieved by the use of various lubricants. One of the simplest and most effective ways to regulate the properties of lubricant compositions is the introduction of additives that can improve the antifriction characteristics.

2. Materials and methods
The Mining University has developed a method of layering different-sized molecules of cationic surfactants, such as quaternary ammonium compounds (QAC), on the metal surface, which allows regulating the physico-chemical and tribochemical characteristics of dispersed metal powders [1, 2]. It is based on the application of the principles of molecular layering, quaternary ammonium compounds such as alkamone (A) and triamone (T) having different-sized alkyl radicals in the nitrogen atom, $C_{16}-C_{18}$ and $C_{1}-C_{3}$, respectively. The selection of preparations was made on the basis of the stabilizing effect of low-molecular-weight QAC in the adsorbed state found earlier in the works [1, 2]. The force and coefficient of friction in the sliding bearing were measured on a tribological stand based on the DM-29M friction machine using a software package in the LabView environment, as well as using mechanical sensors. The experiment was carried out in isothermal conditions in a tribological pair St45 (GOST 1050-88) and Bronze (GOST 18175-78) containing oil I-20 with additives. The load on the bearing varied from 50 to 500 kgf.

3. Study of tribological characteristics of lubricant compositions
Along with the coefficient and friction force, one of the necessary characteristics of the friction process and the lubrication state is the thickness of the lubricant layer (C) at the point of greatest
convergence of the surfaces [3]. The thickness of the oil layer between the rubbing surfaces affects the durability and performance of the mechanism, as well as the possibility of jamming mechanism as a result of too strong convergence rubbing surfaces. In this work the influence of the structure of the adsorption layer samples on the basis of aluminium (PAP-2, particle size less than 1 µm, smallest particles about 45 nm) on the thickness of the lubricating layer of the tribosystem with the lubrication in the form of industrial oil (I-20) with the addition of a modified sample (0.5 masses. %) was studied. The thickness of the lubricating layer was calculated by the Petrov equation:

\[ F = \eta \frac{V A}{c} \]

where \( F \) - the friction force, \( \eta \) - the dynamic viscosity coefficient of the oil, \( V \) - the speed of rotation of the shaft \( (V = \omega R) \), \( A \) - the area of the support surface.

Previously obtained fundamental tribological characteristics, such as force and coefficient of friction (table. 1) showed that the best antifriction effect shows tribosystem with the addition of aluminum powder, processed from a mixture of alcamine and triamone (mass ratio 1:1) [4, 6].

Table 1. Effect of the type of dispersed Al – additive on the equation of the relationship \( F_\text{fr} = \Phi(N) \), the change in \( F_\text{fr} (\Delta F_\text{fr}) \) relative to the starting oil and the friction coefficient \( f \)

| №  | Al – additive or lubrication | Equation \( F_\text{fr} = \Phi(N) \) | \( \Delta F_{1p} \) (medium), % | \( \Delta F_{1p} \) (\( N = 5 \text{ kN} \)), % | \( f \) (\( N = 3.5 \text{ kN} \)) |
|----|-----------------------------|----------------------------------|--------------------------------|--------------------------------|------------------|
| 1  | Al/(A+T)                    | \( y = 0.037x + 12.47 \)        | -11.41                        | -15.92                        | 0.0075           |
| 2  | Al/T/A                      | \( y = 0.048x + 10.81 \)        | -7.75                         | -3.69                         | 0.0079           |
| 3  | Al/A                        | \( y = 0.050x + 12.05 \)        | -1.05                         | -1.4                          | 0.0089           |
| 4  | I-20 (without additives)    | \( y = 0.050x + 12.29 \)        | 0                             | 0                             | 0.0089           |
| 5  | Al/T                        | \( y = 0.050x + 11.86 \)        | -1.52                         | 0.13                          | 0.0087           |
| 6  | Al (ПАП-2)                  | \( y = 0.065x + 11.74 \)        | 12.61                         | 20                            | 0.0101           |

In this paper, the thickness of the lubricating layer was calculated for these systems, depending on the cationic surfactant treatment program. It was observed that surface-modified metal powders increase the thickness of the lubricant layer, ceteris paribus. The values of \( c \) are in the range of 0.04 – 0.06 µm. These data are consistent with the opinion of Rosenberg that the total thickness of the entire possible boundary films, including the oxide, usually less than 0.1 µm [7]. In addition, the fact of boundary friction is confirmed by the fact that with a further increase in the load there is a hook of rubbing surfaces and the transition to dry friction. The values of the friction coefficients \( f \) presented in [4 - 6] are within the permissible limits for boundary friction.
The fact that the introduction of surfactant into the lubricant leads to the increase in the thickness of the boundary layer and helps to reduce wear is a well known fact. For example, it is confirmed, for example, by the results of the work [8]. The analysis of figure 1 leads to a similar conclusion that the introduction of surface-modified aluminum-based powders into industrial oil I-20 increases the value of \( c \). Interestingly, the addition of the original powder PAP-2, not only does not increase, but even reduces the thickness of the lubricant layer. The use of modifiers of alkamone and triamone, as well as their successive application to the sample, provides only a small thickening of the boundary film, relatively pure oil. When the sample Al/(A+T) is introduced into the tribosystem, the greatest increase in the antifriction effect is observed, as well as the thickening of the lubricating layer \( c \). This is most likely due to the conclusions obtained in the work[9] that the lubricating layer of the QAC on the sample of the Al/(A+T) type is most strongly retained on the surface of the solid particle, ensuring the stability of the tribosystem under high loads. Organic hydrophobic radicals in the nitrogen atom in the deposited cationic surfactants, having a small force field [10], provide thickening of the lubricating layer and the easiest sliding of rubbing surfaces. Tribological properties of lubricants with solid additives can be most accurately estimated in the study of boundary friction. Since when approaching the dry friction mode, the antifriction properties of the system are determined by the characteristics of the hardest additive. Selection of the necessary additive affects the behavior of the system under extreme conditions. These additives were also tested using the ARP-11 device in the work [4, 6], some of them are presented in table 2.

**Table 2.** Value of the integral friction index \( D \) for tribosystems with surface-modified aluminum powders

| Additive (powder) | Al/T | Al/A | Al/(A+T) | Al | Al/T/A |
|------------------|------|------|----------|----|--------|
| **D**            | 780  | 910  | 300      | 1690| 1000   |
Control of the nature of interaction in a pair of drill-plate was determined by fixing the integral index $D$, proportional to the magnitude of the acoustic emission arising in contact with friction. The change in the magnitude of the acoustic emission is proportional to the change in the friction force in the pair (coefficient of friction) and by its value it is possible to estimate the nature of friction. The data of table 2 and [4, 6] confirm that the greatest decrease in the tribological characteristics occurs in the system containing the additive of aluminum powder with adsorbed alkamon and tremona from the mixture, and the smallest system with aluminum PAP-2.

4. Conclusion
The process of increasing the thickness of the boundary layer of the lubricant composition in transmissions and other mechanisms is an important task, as it reduces the wear of friction parts, as well as pushes the boundary of dry friction, thereby improving the stability of the equipment. Despite this, the study of boundary friction is also important for the study of the effect of solid additives on the extreme properties of lubricants. In the work, modified samples were identified that can increase the thickness of the lubricant layer, thereby improving the anti-friction characteristics of the system.

References

[1] Syrkov A G 2013 Russian Journal of General Chemistry 83 N8 1392-1394
[2] Syrkov A G, Fadeev D V, Taraban V V, Silivanov M O 2014 Condensed matter and interphase boundaries 16 N2 215-219
[3] Raiko M V 1970 Gear lubrication 196
[4] Taraban V V, Syrkov A G, Silivanov M O, Nazarova E A 2015 Chemical physics and mesoscopy 17 N4 557-564
[5] Nazarenko M Y, Kondrasheva N K, Saltykova S N 2017 Tsvetnye Metally 7 29-33
[6] Syrkov A G 2015 Russ. J. Gen. Chem. 85 N6 1538-1539.
[7] Rozenberg Yu A 1972 The effect of lubricating oils on the reliability and durability of machines 524
[8] Beliy V A 1989 The role of the structure of the surface layers in the external friction of polymeric materials 115
[9] Syrkov A G, Sychev M M, Silivanov M O, Rozhkov N N 2018 Glass Physics and Chemistry 44 N5 474-479
[10] Abramson A A, Shchukin E D 1984 Surface phenomena and surfactants (Leningrad)