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RESEARCH

Dependence of Wear Intensity on Parameters of Tribo Units

Ye. Ventsel[a], O. Orel[a], O. Shchukin[a], N. Saienko[a], A. Kravets'[b]

[a] *Kharkiv National Automobile and Highway University, Yaroslava Mudrogo st, 25, Kharkiv, Ukraine, 61002.*
[b] *Ukrainian State University of Railway Transport, Feierbakh Square 7, Kharkiv, Ukraine, 61050.*

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Corresponding author:

Oleksandr Shchukin
Kharkiv National Automobile and Highway University, Yaroslava Mudrogo st, 25, Kharkiv, Ukraine, 61002.
E-mail: alexhome88@gmail.com

A B S T R A C T

The degree of dispersion of particles of pollution and their amount in the lubricating medium substantially affects the anti-wear properties of the latter. At the same time, if the particle size of the contaminants is 5 microns or less, the anti-wear properties of such a lubricant medium are improved and, consequently, the wear of the friction surfaces decreases. The equation for the wear rate is obtained taking into account the interaction of charged wear particles with friction surfaces. It is shown that on the basis of the obtained equation, the wear rate can be presented as a decreasing function of the coefficient of the lubricant anti-wear properties, which is the ratio of concentrations of finely dispersed to coarsely dispersed particles.

1. INTRODUCTION

The study of tribo systems always requires an integrated approach to the problems connected with them due to the multicomponent, multifactor nature and openness of such systems. The latter feature stipulates the main methodological principle of the research – the thermodynamic approach to the analysis of open systems.

The thermodynamic approach was based on the following ideas [1-3]:

- in the surface layer of the wearable material, one can distinguish the volume being in the state of the local equilibrium;
- processes of friction and wear can be described by the equations of energy balance;
- the rate of destruction is controlled by the rate of entropy generation, that is, entropy production.

2. PURPOSE OF THE STUDY

Establishing the relationship between the rate of wear of the friction surface and the degree of dispersion of wear particles, which is characterized by certain technical parameters.

3. ANALYSIS OF THE PROBLEM

The method for investigating dissipative processes of various nature is based on the well-known I. Prigozhin's theorem on the minimization of entropy production, the methods of this theorem application to friction processes was described in [1,3].

For the first time, the equation that links entropy production in tribo units with taking into account the lubricating medium was proposed in [4]. But in this equation there is no direct relation between the degree of dispersion of pollution particles in the lubricating medium with the intensity of tribo units wear. In this connection, we analyzed the work of tribo units that contain the lubricating medium and in which the processes of transferring entropy and substance take place. The generalized equations of balance for such processes take the form:

$$\frac{\partial \rho_s}{\partial t} + div\vec{J}_S = ps \tag{1}$$

$$\frac{\partial n_v}{\partial t} + div\vec{J}_N = Wn \tag{2}$$

where: ρ_s – volumetric entropy density, $\vec{J}_S$ – entropy flow density, p_s – power of entropy sources density which is called entropy production, n – volumetric concentration of pollution particles, $\vec{J}_N$ – density of the wear particles flow, Wn – power of density of wear particles generation sources, that is, the number of particles which appear in the unit of volume of the tribo unit per a time unit.

For the stationary process of the tribo unit, the derivatives with time are equal to zero, and the previous equations take the form:

$$div\vec{J}s = ps \tag{3}$$

$$div\vec{J}n = Wn \tag{4}$$

For the stationary friction mode, we can formulate the equation of balance for wear particles, based on the following ideas:

1. If the friction surfaces generate n_o particles in the unit of volume per a time unit, and at the same time, n_{ex} particles are carried away from the tribo unit, and inside the unit n_{gi} particles are generated due to internal processes, then in the gap of the tribo unit there are particles n_v whose number satisfies the equation:

$$n_v = n_0 - n_{ex} + n_{gi} \tag{5}$$

2. The presence of charged particles in the tribo unit, the cause of their emergence being described below, requires consideration of their concentration n_q in the overall balance of wear particles concentration. The concentration of charged particles in finely dispersed aerosol systems, according to [5], varies from 0.4 to 0.75 of the total concentration in the range of the particles size 0.3 – 0.7 μm, so it can be assumed that:

$$n_q = k_q n_V \tag{6}$$

where the coefficient of proportionality k_q takes characteristic values from 0.4 to 0.75 in the specified range of sizes [5].

In paper [6] the methods of calculating entropy production for the model of electrostatic interaction of finely dispersed wear particles with a friction surface are described. It was assumed that finely dispersed particles are usually charged [7]. The cause of the finely dispersed particles becoming charged is explained by a variety of processes in the frictional contact: radiation of particles by electromagnetic and other types of ionizing radiation, thermionic emission and the exchange of the charged particles with the surrounding medium, if the chemical potentials of the charged particles and medium are different. These are the two latter processes that are usually realized in the tribo units and are characterized by a high local temperature and by a difference of chemical potentials between wear particles and the lubricating fluid or elements of secondary structures [8].

The charge q of the dispersed particles is related to their size a by formula [7]:

$$q = 4\Pi\pi\varepsilon_0\varepsilon\phi_0 a \cdot \exp\left(-\frac{a}{D}\right) \tag{7}$$

where: ε – dielectric penetrability of the medium ($\varepsilon_o = 8{,}854 \cdot 10^{-12}$ F/m – electric constant); ϕ_0 – output potential, B; a - the size of the pollution particles, m; D – the length of Debye screening of charged particles, m.

Entropy production in accordance with the general content of this value can be given in the form:

$$p_s = \int \vec{X}_q d\vec{j}_q \tag{8}$$

where: $\vec{j}_q$ – density of the flow of the charged wear particles; $\vec{X}_q$ – the thermodynamic force that causes this flow.

According to [1], the thermodynamic force for this case is determined according to the equation:

$$\vec{X}_q = -\frac{grad\phi}{T} \tag{9}$$

where: ϕ – the electric potential of the field of the electrostatic image forces.

The mechanism of emergence of this field acts due to the fact that the charged finely dispersed particles which are located in the gap of the tribo unit on small (of the order of several Debye screening lengths D) distances from the surface, induce the electric charges of the opposite sign in the leading material of the tribo unit, which results in emergence of forces of electrostatic image between the charged particles and the surface of the tribo unit that causes the electric current of the charged particles. It can be assumed that the particle-image creates an electric field, which is described by the Debye's potential.

$$\phi_D = \frac{q}{4\pi\varepsilon_0\varepsilon r}\exp\left(-\frac{r}{D}\right) \tag{10}$$

In this case, the original particle moves in this field.

In view of the rapid decrease of the Debye potential, it can be taken as equal to zero, starting with the distance z′ from the friction surface for which z′ >> D. At all points that satisfy this condition, the rate v_z of the particle-original, which is provided by electrostatic interaction, is equal to zero, since such interaction between the particle-original and the particle-image is insignificantly small. Under the action of the Debye field, the particle-original moves perpendicularly to the friction surface, approaching it at a minimum distance δ, which is determined by the thickness of the surface adsorbed layer that forms a double electric layer – a thin surface layer composed by spatially separated electric charges of opposite signs that appears at the boundary of two phases. The double electric layer can be considered as a kind of a micro-capacitor, the distance between its plates being determined by the size of charges that make up this layer. The average value of the dense part of the double electric layer is approximately equal to the size of the charged objects – finely dispersed particles of impurities, that is:

$$\delta \approx a \tag{11}$$

Since the acceleration of the particle-original occurs at a short distance, the work of forces of viscous friction can be neglected. Then the difference between the Debye potentials between the point z′, where φ (z′) = 0 and the point that is distanced by the value δ from the nominal surface of the tribo unit, is equal to the kinetic energy of the particle divided by the charge, i.e.

$$q\Delta\phi = \frac{q^2}{4\pi\varepsilon_0\varepsilon\cdot 2\delta}\exp\left(-\frac{2\delta}{D}\right) = \frac{mv_z^2}{2} \tag{12}$$

Proceeding from this equation, in [9], entropy production dp_{sq} was found in the range of sizes da of the charged dispersed particles which move under the action of charges induced in metals:

$$dp_{sq} = 4\pi\left(\varepsilon_0\varepsilon\right)^2 \phi_0^3 a^{3/2}\left(\frac{1}{\delta}+\frac{1}{D}\right) \times\frac{\exp\left(-3\frac{a}{D}-2\frac{\delta}{D}\right)\sqrt{\frac{3}{\varepsilon_0\varepsilon\rho}}}{\delta^{3/2}T} f\left(a\right)da \tag{13}$$

where: $f(a) = \frac{dn_V}{n_V da}$ is the function of pollution particles distribution by size.

4. PROBLEM SOLUTION

Let us consider the process of wear, which is stipulated by carrying the wear particles with the concentration of n_{ex} away from the tribo unit. According to paper [6], the density of the wear particles flow along the axis z is:

$$d\vec{J}_N = n_{ex}\left(\frac{\sigma_{fr}}{2\pi\rho n_0 I a^3}\right)^{1/2}\vec{k}f(a)da \tag{14}$$

The thermodynamic force which causes this flow should be determined by the equation:

$$\vec{X}_N = -\frac{\sigma_{fr}}{ITn_{ex}^2} gradn \tag{15}$$

where: I – intensity of wear, σ_{fr} – specific frictional force.

When quantifying the value $gradn$, we assume that the concentration of impurity particles at the exit of the tribo unit is much smaller than the concentration n_o near the friction surface, due to this the value $gradn$ takes the form:

$$gradn = \frac{n_0}{2R_{\max}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_C}{HB}\right)^{1/v}\right]} \tag{16}$$

where: p – contour pressure, HB – hardness, $R_{\max}$ – maximum distance between the surfaces of wear, a_0, b_0 – parameters of the curve of the support surface.

But it should be noted that not all wear particles contained in the tribo unit are involved in the flow (n_V) but only those that are carried away from it, and the concentration of the latter is equal to n_{ex}. As to the estimation of the value $gradn$, it should be noted that it will be more accurate if we take into account the particles that go beyond the boundary of the tribo unit (their concentration is equal to n_{ex}), and then the ratio for estimating the value $gradn$ takes the form:

$$gradn = \frac{n_0 - n_{ex}}{2R_{\max}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_C}{HB}\right)^{1/v}\right]} \tag{17}$$

According to equation (8), due to the wear process on account of the particles that are carried away from the tribo unit, entropy production starts, which is determined by equation:

$$dp_{sN} = -\left(\frac{\sigma_{fr}}{Ia}\right)^{3/2} \times \frac{n_0 - n_{ex}}{2R_{\max}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_C}{HB}\right)^{1/v}\right]\sqrt{2\pi\rho n_0}\cdot n_V T} f(a)da \tag{18}$$

Despite the fact that production of the entropy is essentially a positive value, in this case it takes a negative value, because it is carried away from the tribo unit. The "pumping out" of entropy was mentioned earlier, for example, in [10]. From equations (13) and (18) one can determine partial derivatives of bot12h components of entropy production p_{sq} and p_{sN} by particle sizes. These derivatives have a look:

$$\frac{\partial p_{sq}}{\partial a} = 4\pi(\varepsilon_0\varepsilon)^2 \phi_0^3 a^{3/2}\left(\frac{1}{\delta}+\frac{1}{D}\right) \times \frac{\exp\left(-3\frac{a}{D}-2\frac{\delta}{D}\right)\sqrt{\frac{3}{\varepsilon_0\varepsilon\rho}}}{\delta^{3/2}T} f(a) \tag{19}$$

$$\frac{\partial p_{sN}}{\partial a} = -\left(\frac{\sigma_{fr}}{Ia}\right)^{3/2} \times \frac{n_0 - n_{ex}}{2R_{\max}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_C}{HB}\right)^{1/v}\right]\sqrt{2\pi\rho n_0}\cdot n_V T} \times f(a)da \tag{20}$$

The sum of partial derivatives from production of the entropy p_{sq} and p_{sN} is a partial derivative from their sum:

$$p_s = p_{sq} + p_{sN} \tag{21}$$

Equation $\frac{\partial p_s}{\partial a}$ is a prerequisite for the extremum of the function of several variables (for production of the entropy, this extremum is the minimum in accordance with I. Prigozhin's theorem). In this connection, from equations (19) – (21) with account of $\frac{\partial p}{\partial a}$ one can determine the intensity of wear, which is equal to:

$$I = \frac{\sigma_{fr}(n_0 - n_{ex})^{1/3}\lambda^{2/3}\delta^{5/3}\exp\left(2\frac{a}{D}+\frac{4\delta}{3D}\right)}{2,28\varepsilon_0\varepsilon a^2\phi_0^2(\lambda+\delta)^{2/3}\cdot R_{\max}^{2/3}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_C}{HB}\right)^{1/v}\right]^{2/3} n_{ex}^{4/3}} \tag{22}$$

As it is known, in addition to intensity the wear rate i_v is also used. The latter characteristic is, in this case, more convenient than the intensity I, since the wear rate is defined as the rate of reducing the friction surface thickness with time:

$$i = \frac{dh}{dt}$$

Reducing the concentration of wear particles with time is also a time derivative. There is an obvious connection between these two characteristics of the wear process:

$$I = \frac{i_V}{u} \tag{23}$$

where u is the relative speed of sliding by the friction surface.

During the analysis of processes that occur in a mechanical assembly with the relative motion of surfaces, we proceed from the most general definition of the frictional force F_{fr}, as a derivative of the dissipative function D^* by the generalized rate $\dot{l}$:

$$F_{fr} = \frac{dD^*}{d\dot{l}} \tag{24}$$

Such a definition of the frictional force is used, for example, in [6,9], and taking into account the relation between the dissipative function, production of the entropy p_S and temperature T, it takes the form:

$$D^* = p_s \cdot T \tag{25}$$

This equation allows to receive a connection between the specific frictional force σ_{fr} and production of the entropy in the following form:

$$d\sigma_{fr} = \frac{hT}{u} dp_s \tag{25}$$

where: h is thickness of the deformed layer of friction, m.

The main contribution to production of the entropy by the ensemble of wear particles within the framework of this model is the energy dissipation due to their electrical interaction with the surface of friction. It is precisely this part of entropy production that is related to friction, since the removal of entropy from a tribo system with wear particles, as expressed by formula (18), cannot affect the frictional force.

Then, inserting $p_s = p_{sq}$ into equation (25), which is expressed by equation (13), and integrating the obtained equation, we receive:

$$\sigma_{fr} = \frac{4\pi h}{u} \times \int_0^{a_{\max}} n_q \left(\frac{\varepsilon_0 \varepsilon}{\delta}\right)^{3/2} \phi_0^3 \left(\frac{a}{\delta} + \frac{a}{\lambda}\right) \sqrt{\frac{3a}{\rho}} \cdot \exp\left(-3\frac{a}{D} - 2\frac{\delta}{D}\right) f(a)\,da \tag{26}$$

We will estimate the integrand function, taking into account that $\frac{a}{\delta} \approx 1$, and the value of the length D of the Debye shielding according to [11] is determined by the formula:

$$D = \frac{1}{2q}\sqrt{\frac{\varepsilon_0 kT}{\pi n_V}} \tag{27}$$

It should be noted that, according to equation (7), charge q is a function of D. A numerical solution of equations (7) and (27) given in [12] showed that the ratio $\frac{a}{D} << 1$, and does not practically depend on the size of finely dispersed particles. These facts lead to the conclusion about a weak dependence of the value $\exp\left(-3\frac{a}{D} - 2\frac{\delta}{D}\right)$ on a. As in the range of submicron sizes the density of particles is linearly diminished with their size [5], $\sqrt{\frac{a}{\rho}}$ can also be considered as a weakly variable value, and then we have:

$$\int_0^{a_{\max}} n_q \left(\frac{\varepsilon_0 \varepsilon}{\delta}\right)^{3/2} \phi_0^3 \left(\frac{a}{\delta} + \frac{a}{\lambda}\right) \sqrt{\frac{3a}{\rho}} \exp\left(-3\frac{a}{D} - 2\frac{\delta}{D}\right) f(a)\,da$$
$$\approx n_q \left(\frac{1}{\delta} + \frac{1}{D}\right) \exp\left(-3\frac{a}{D} - 2\frac{\delta}{D}\right) \times \sqrt{\frac{3a}{\rho}} \left(\frac{\varepsilon_0 \varepsilon}{\delta}\right)^{3/2} \phi_0^3 \int_0^{a_{\max}} af(a)\,da \tag{28}$$

Due to rapid decrease of the distribution function $f(a)$ after the maximum size of particles, we can assume that:

$$\int_0^{a_{\max}} af(a)\,da \approx \int_0^{\infty} af(a)\,da \tag{29}$$

Here the integral on the right side is the average size $\bar{a}$ of particles.

Thus, we have the following approximation for the specific frictional force:

$$\sigma_{fr} = \frac{4\pi h}{u} n_q \left(\frac{1}{\delta} + \frac{1}{\lambda}\right) \exp\left(-3\frac{a}{D} - 2\frac{\delta}{D}\right) \times \sqrt{\frac{3a}{\rho}} \left(\frac{\varepsilon_0 \varepsilon}{\delta}\right)^{3/2} \phi_0^3 \cdot \bar{a} \tag{30}$$

Inserting equation (23) in (22), and taking into account (2.20), we have the following equation for the rate of wear:

$$i_v = \frac{4\pi h\bar{a}\left(\frac{1}{\delta}+\frac{1}{D}\right)\exp\left(-3\frac{a}{D}-2\frac{\delta}{D}\right)\sqrt{\frac{3a}{\rho}}\varphi_0 D^{2/3}\delta^{5/3}}{2,28\varepsilon_0\varepsilon\left(\frac{\varepsilon_0\varepsilon}{\delta}\right)^{-3/2}a^2(D+\delta)^{2/3}} \times \frac{\exp\left(2\frac{a}{D}+\frac{4\delta}{3D}\right)n_q(n_0-n_{ex})^{1/3}}{R_{\max}^{2/3}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_c}{HB}\right)^{1/v}\right]^{2/3} n_{ex}^{4/3}} \quad (31)$$

Since, according to the data given above, it was determined that $\frac{a}{D} << 1$ and $a \approx \delta$, the product of the exponents in the numerator is close to one. In addition, taking into account the fact that the thickness δ of the surface adsorbed molecular layer is substantially smaller than the length D of the Debye screening, we come to the conclusion that $\frac{1}{\delta} >> \frac{1}{D}$. These facts allow to present the previous equation after the corresponding simplication and substitution $\varepsilon_o = 8{,}854\cdot 10^{-12}$ F/m in the form:

$$i_v = 2{,}8\cdot 10^{-5} h \times \frac{\phi_0\sqrt{\varepsilon}}{\sqrt{\rho a}\cdot\delta^{5/6}R_{\max}^{2/3}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_c}{HB}\right)^{1/v}\right]^{2/3}} \times \frac{n_q(n_0-n_{ex})^{1/3}}{n_{ex}^{4/3}} \quad (32)$$

Let us consider the structure and properties of the final multiplier of this equation, which is a function of only the concentration itself:

$$f(n) = \frac{n_q(n_0-n_{ex})^{1/3}}{n_{ex}^{4/3}} \quad (33)$$

Taking into account equation (6), we receive:

$$f(n) = \frac{k_q\left(1-\frac{n_{gi}}{n_V}\right)^{1/3}}{\left(n_{ex}/n_V\right)^{4/3}} \quad (34)$$

As is seen from (34), $f(n)$, and together with it the wear rate decrease with increasing values of concentration n_{gi} and n_{ex} that belong to the finely dispersed area of wear particles. On the contrary, the increase in total concentration n_V leads to increase of the wear rate. This kind of dependence i_v on the concentration of individual groups of particles allows to consider the value $\theta = \frac{n_{ex}}{n_V}$ as a coefficient of anti-wear properties of the lubricating medium [7]. In this case, the equation for the rate of wear takes the form:

$$i_v = 2{,}8\cdot 10^{-5} h \frac{\phi_0\sqrt{\varepsilon}}{\sqrt{\rho a}\cdot\delta^{5/6}R_{\max}^{2/3}\left[1-\left(\frac{a_0}{b_0}\cdot\frac{p_c}{HB}\right)^{1/v}\right]^{2/3}} \times k_q\frac{\left(1-\frac{n_{gi}}{n_V}\right)^{1/3}}{\theta^{3/4}} \quad (35)$$

As is seen from (35), the rate of wear is influenced radically by the concentration of particles of various types of pollution, with the greatest values of $\frac{n_{gi}}{n_V}$ and θ. The size of the particles does not affect this value significantly because the dielectric constant ε in the numerator increases with increasing *a* [9] in the denominator. As is obvious from (35), the growth of the fraction of particles generated inside the tribo unit can reduce the wear rate to any small values. But if the practical estimation of this value has certain difficulties, then the value $\theta = \frac{n_{ex}}{n_V}$ can be regarded as a fraction of finely dispersed particles in the complete ensemble of particles of impurities and contaminants, because of the fact that mainly finely dispersed particles are carried away from the tribo unit. This value can be related to the practically applied value of the coefficient of anti-stress properties k_j, as the ratio of the number of finely dispersed particles to the number of the rest of the particles, that is:

$$k_j = \frac{n_d}{n_V - n_d} \quad (36)$$

where: $n_d \approx n_{ex}$ – the volume concentration of finely dispersed particles.

In this case, it is obvious that there is a relationship between the anti-wear parameter θ and the coefficient of anti-wear properties k_j in the form of a correlation:

$$\theta = \frac{k_j}{1+k_j} \tag{37}$$

The equation for the wear rate of the tribo unit takes the form:

$$i_v = 2{,}8\cdot10^{-5} h \frac{\varphi_0\sqrt{\varepsilon}}{\sqrt{\rho a}\cdot\delta^{5/6} R_{\max}^{2/3}\left[1-\left(\dfrac{a_0}{b_0}\cdot\dfrac{p_c}{HB}\right)^{1/v}\right]^{2/3}} \times k_q n_V^{1/3}\left(1-\frac{n_{gi}}{n_V}\right)^{1/3}\left(1+\frac{1}{k_j}\right)^{4/3} \tag{38}$$

This equation is correlated with the results of studies [11], which prove a decrease in the wear intensity of the tribo units of the hydro system due to improvement of anti-wear properties of the working fluid of the hydraulic drives with a higher value of the coefficient k_j.

The direct calculation of the wear rate by formula (38) encounters the difficulties caused by the lack of certainty as to a number of parameters included in this formula (for example, the thickness of the double electric layer δ, the size of the dispersed particles *a*, their concentration n, etc.). To avoid these difficulties, one can find the connection between the relative changes in the values i_v and k_j, based on the fact that in the stationary state, which corresponds to the working mode, the main tribotechnical characteristics of the tribo unit do not undergo significant changes, and it can be assumed that the parameter that impacts the wear process significantly is the coefficient k_j. In this case, logarithmic differentiation allows to determine the relationship between the relative value of the wear rate and the coefficient of anti-wear properties k_j:

$$\frac{\Delta i_v}{i_v} = -\frac{4}{3}\frac{\Delta k_j}{\left(1+k_j\right)k_j} \tag{39}$$

The minus sign in this formula indicates a decrease of the wear rate with an increase of the coefficient of anti-wear properties.

The validity of the dependence (39) is confirmed by the results of operational tests of the motor grader GR 165.

After the hydrosystem was filled with fresh working fluid Hydro HV 46, the systematic sampling of the working fluid was carried out to determine the granulometric composition of the particles and content of iron in it.

Based on the results of the determination of the working fluid granulometric composition, with the help of which the value of the coefficient of anti-wear properties K_j was found, the right side of the expression (39) was calculated. In addition, according to the content of iron in the working fluid Hydro HV 46, its mass was calculated and, accordingly, the wear rate (the left side of expression (39)).

After calculating both sides of equation (39) the difference between the results of theoretical and experimental studies was determined, which according to the calculations over the whole period of operation of the working fluid in the hydraulic drive makes up from 10 % to 20 %.

For example, by the content of iron and the working fluid operation time of 85 and 280 machine-hours, and 660 and 750 machine-hours, two rates of wear were obtained: i_{v1} = 1.506×10^{-3} g/machine-hours and i_{v2} = 4.547×10^{-3} g/machine-hours. From these two wear rates, Δi_v was calculated as the difference between them, and i_v as the average of two rates. By taking the corresponding values of K_j for the same operation time (K_j = 1.16 and 0.36 units), ΔK_j, was calculated as the difference between the values and the average between them. Inserting the obtained results of calculations into equation (39), it was found that the value of the left side of the equation is 1.005, and the right side – 0.80 (the difference is 20.4 %).

Similarly, taking the values of the iron content and the coefficient K_j with the operation time of the working fluid of the motor grader hydraulic actuator 85-280 machine-hours and 1200-1230 machine-hours, and inserting the obtained results of the calculations into equation (39), it was found that the value of the left-hand side of the equation is 1.375, and the right-hand one is 1.521 (the difference is 9.6 %).

5. CONCLUSION

The degree of particles dispersion, their concentration and the nature of the concentration distribution by the particle sizes have a significant effect on the physical and mechanical properties of the friction pairs (mainly on the frictional force and wear intensity). In this connection, the problem of correlation between the characteristics peculiar to dispersed particles of impurities (especially those that are finely dispersed and electrically charged) and the tribological characteristics of the tribo unit (primarily by the frictional force and intensity (rate) of wear) was considered. The analysis of the processes occurring in tribo units always requires an integrated approach to the problems associated with them, due to the multicomponent, multifactor nature and openness of such systems. The latter feature stipulates the main methodological principle of the research – the thermodynamic approach to the analysis of open systems.

Summary:

1. For the stationary mode of friction, the equation of balance of wear particles is formulated.
2. The equations for determining the value of the gradient of the wear particles concentration inside the tribo unit and the wear rate with account of interaction of charged wear particles with the surfaces of friction are obtained.
3. It is shown that on the basis of the obtained equations, the wear rate can be presented as a decreasing function of the coefficient of anti-wear properties, which is the ratio of the concentrations of finely dispersed to coarsely dispersed particles.

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