# ANTI-SCUFFING PROPERTIES OF OILS AS A FUNCTION OF THE RATE OF THEIR DECOMPOSITION IN THE FRICTION ZONE

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Fig. 1

Figure 1: Fig. 1

## Abstract

## Full Text

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# ANTI-SCUFFING PROPERTIES OF OILS AS A FUNCTION OF THE RATE OF THEIR DECOMPOSITION IN THE FRICTION ZONE

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Up to the present time there are no reliable parameters suitable for engineering calculations of friction units with respect to scuffing. Such generally known characteristics as the critical scuffing load $P_k$ or the specific scuffing load $\sigma_k$, obtained in tests on friction machines, prove to be of little use, especially considering that the numerical value of these parameters depends on the design of the apparatus, the speed, the temperature, and the shape and dimensions of the rubbing elements.

The author believes that the question of parameters for evaluating the anti-scuffing properties of oils can be solved if the scuffing process is considered from a point of view different from the generally accepted one.

In a number of works $(1, 2, 5)$ and others it has been shown that, in the process of friction, lubricating materials, as a result of the action of the high temperature in the friction zone and the catalytic action of the metal, undergo profound chemical changes. In particular, it has been shown (1) that processes of oxidation, polymerization, and thermal decomposition of oils take place.

**Fig. 1.** $a$—diagram of the friction unit: 1—plate, 2—slider, $P$—load on the slider, $v$—speed of motion of the slider. $b$—friction surface of the slider of complex geometrical shape: $n$—$n$—direction of motion, $l$—length of the slider adopted for calculations according to equation (2).

The final products of the multistage transformations of mineral oils are both gaseous products and products insoluble in the oil from hydrocarbon condensation: carbon, graphite, and compounds of carbon with metal (2). Naturally, the rate of these transformations increases with increasing temperature in the zone of sliding contact, and it may be asserted that at a sufficiently high temperature the rate of transformation of the original oil into final products will become so high that all the oil entering the contact zone (during its residence time in this zone) can be transformed into products incapable of ensuring a low coefficient of friction.

Let a metallic slider 2, pressed against the surface by a force $P$, move with velocity $v$ over a metallic surface 1 (Fig. 1) covered with a thick layer of oil. We shall assume that the oil wets both friction surfaces and that, under the specified conditions, a hydrodynamic lubrication regime does not arise; instead, lubrication takes place characterized by the presence of contact of asperities of the mating surfaces (Fig. 1a), by a coefficient of friction $f$, and by a temperature in the contact zone $T_1$. When the slider moves, the oil filling the depressions between the contacting asperities enters the friction zone. This oil is a reserve ensuring—

ensuring the continuous supply of lubricant to the contact sites of microprotrusions.

If the load on the slider is increased, then up to a certain limit its gradual increase is accompanied by a gradual increase in temperature in the contact zone, while the coefficient of friction changes little. Upon reaching a certain critical value of the load (for the given oil and friction conditions), the coefficient of friction increases abruptly (severalfold), and at the same time the temperature in the friction zone rises sharply. Scuffing of the rubbing surfaces occurs, accompanied by their considerable damage.

In accordance with the above, the phenomenon of scuffing occurs under the condition that the rate of chemical transformations of the oil (its decomposition, aging) reaches such a value that all the fresh oil entering the friction zone at point $B$ (Fig. 1a) is completely decomposed (loses its oil properties) by the time the slider moves from position $AB$ to position $A'B'$. Owing to the absence of oil, the coefficient of friction at point $A'$ rises sharply; this is accompanied by a sharp increase in temperature, by the spread of the zone of elevated temperature in the direction of point $B'$, by acceleration of the decomposition process of newly entering oil, and by the spread of scuffing over the contact surface. In those cases where the rate of decomposition of the oil in the friction zone is so low that, during the time the slider moves from position $AB$ to position $A'B'$, the oil does not lose its ability to separate the rubbing surfaces, scuffing does not occur.

According to the hypothesis set forth, the characteristic of the anti-scuff properties of an oil is the rate $V$ of its chemical transformation in the friction zone into products incapable of performing the function of a liquid lubricant (the rate of decomposition in the friction zone). The relation between the value $V$ and temperature should be expressed by the Arrhenius equation

$$\lg V = A - B/T, \tag{1}$$

where $A$ is a constant; $B = E/2.3R$ ($E$ is the activation energy, $R$ the universal gas constant); $T$ is the absolute temperature in the friction zone.

Verification of the applicability of equation (1) to the processes occurring in the oil in the sliding-friction zone during scuffing of surfaces, and consequently of the correctness of the proposed hypothesis, reduces to finding the values $V$ and $T$ from experimental data on the evaluation of the anti-scuff properties of oils, if the calculation is based on equality of the rates of supply and decomposition of the oil in the friction zone at the moment of scuffing.

For the case shown in Fig. 1, the time for the slider to move from position $AB$ to position $A'B'$ is $\tau = l/v$, where $l$ is the length of the slider and $v$ is the velocity of motion of the slider.

If the amount of oil that can enter the friction zone by capillary forces and a possible hydrodynamic effect is neglected, then the volume of oil entering the friction zone and consumed during the time $\tau$ at scuffing is $Q = alh$, where $a$ is the width of the slider and $h$ is the average thickness of the oil layer contained in the depressions between the friction surfaces.

The average rate of oil decomposition at which scuffing of two surfaces occurs is determined by the equation $V' = alh/\tau$ cm$^3$/sec. It follows from this that $V'$ depends on the dimensions of the contact area and on the value $h$, i.e., it is different for different friction pairs.

If $V'$ is referred to a unit volume of the space between the friction surfaces, we obtain an invariant value of the oil decomposition rate, $V = V'/alh$. The quantity $V$ represents the average rate of decomposition of oil in the space between surfaces moving relative to one another, for values of $a$, $l$, and $h$ equal to unity, equivalent to the rate of decomposition in an actual friction pair during scuffing.

Transforming the last equation, we finally obtain

$$V = v/l. \tag{2}$$

It follows from equation (2) that $V$ is a function only of the sliding velocity and the length of the slider. In cases where the slider has a complex geometric shape, the value of $l$ is determined by the length of the section where the friction path is greatest (Fig. 1b).

Thus, using equation (2), it is easy to determine the rate of decomposition of the oil in the friction zone during seizure. The second quantity of interest to us—the temperature in the friction zone at the moment seizure begins (the transition temperature)—can be calculated using the equations of Blok, Jaeger, and others ([3]).

The author calculated $V$ and $T$ for a number of oils from test data obtained on four-ball friction machines by the one-minute method (balls of ShKh-9 steel

Figure 2

Figure 2: Figure 2

with diameters of 9.52, 12.7, and 19 mm). For each test, a fresh portion of oil was taken. The value of $l$ in equation (2), equal to the diameter of the elastic contact spot between the balls under load $P_k$, was calculated from the Hertz formulas, and the temperature rise at the contact spot from Blok' s equation.

**Fig. 2.** Dependence of the average rate of oil decomposition on the temperature in the friction zone (tests on a friction machine with balls of 9.52 mm diameter)

1 —mineral oil MK-22:
*a* —sliding velocity 35 cm/sec, temperature at the start of the test 160, 130, 100, 75, and 45°;
—26 cm/sec, 160, 130, 100, 45, and 20°;
—17.4 cm/sec, 160, 130, 100, 45, and 20°;
—8.68 cm/sec, 130, 100, 75, and 20°;
—4.34 cm/sec, 100, 75, and 45°.

2 —the same oil with an anti-seizure additive:
—35 cm/sec, 130, 100, 75, and 20°;
—26 cm/sec, 130, 100, 45, and 20°;
—17.4 cm/sec, 130, 100, 45, and 20°.

3 —mineral spindle oil AU:
—35 cm/sec, 45, 20, and −20°;
—26 cm/sec, 20°;
—17.4 cm/sec, 45, 20, and −20°;
—8.68 cm/sec, 45, and 20°.

4 —the same oil with an anti-seizure additive: temperature at the start of the tests 20°; sliding velocities are the same as for the corresponding points on curve 3.

The relationship between the rate of oil consumption, calculated from equation (2), and the absolute temperature in the friction zone is described quite well by the Arrhenius equation (Figs. 2 and 3). The consumption rate of the oils studied does not depend on the test temperature, the sliding velocity, or the ball size.

For oils without additives, the activation energy varies from 4.6 kcal/mol (MS-20) to 13.5 kcal/mol (spindle AU). The comparatively small value of the activation energy confirms the correctness of the assumptions (2) concerning the catalytic action of the metal on the processes of chemical transformation of the oil in the friction zone. The introduction into oils of an anti-seizure additive (containing 20% sulfur and 27% chlorine) leads to a sharp change both in the rate of oil decomposition and in the activation energy (Fig. 2).

The investigation carried out shows that the principal characteristic of an oil determining its ability to prevent seizure of rubbing surfaces is the rate of decomposition in the friction zone—the rate of chemical transformation of the oil from its initial state into final products that are unable to perform the function of a liquid lubricant. Seizure of friction surfaces occurs when the rate of oil decomposition is equal to or greater than the rate at which it enters the friction zone.

The constants of equation (1) can be used as parameters for evaluating the anti-seizure properties of oils, which opens up the possibility of calculating friction units for seizure.

Known experimental data on the dependence of the seizure load on the chemical composition of metallic surfaces ($^4$), on the stepwise change of this load with changes in bulk temperature, and other considerations indicate that the parameters of equation (1) for each oil, in the general case, do not remain constant. A change in the friction conditions (bulk temperature of the oil, chemical composition of the metal, gaseous medium) can lead to qualitative changes in the process of oil transformations in the friction zone and, as a consequence, to a change in the activation energy and in the constant $A$ in equation (1).

**Fig. 3.** Dependence of the average rate of oil decomposition on the temperature in the friction zone.
**1** –mineral oil MS-20: *a* –ball diameter 12.7 mm, 57.6 cm/sec, 20°; *b* –19 mm, 25.9 cm/sec, 100, 75, 50 and 20°.
**2** –machine oil SU: *v* –12.7 mm, 20°, 17.3 and 57.6 cm/sec; *g* –19 mm, 25.9 cm/sec, 100, 50 and 20°.

The results of the present study indicate the need to reconsider existing ideas about the role and mechanism of action of anti-seizure additives to oils, proceeding from the fact that their main purpose is to inhibit the processes of oil decomposition in the friction zone. Of great importance is the clarification of the role of additives as agents that lower the catalytic activity of the metal. In the light of this study, the influence of the gaseous medium (including atmospheric oxygen) on the seizure process of friction surfaces must be interpreted in a new way.

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*Note: Figure translations are in progress. See original paper for figures.*