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MODELING OF THE MECHANISM OF ACTION OF EPILAME FILM IN THE PROCESS OF PROCESSING

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Abstract:
The article discusses the mechanism of action of the epilam film during the operation of epilated drills and the influence of cutting conditions, processing conditions on their condition. Tribological tests were carried out using a special installation, where the test conditions are close to the conditions characteristic of the drilling process. Based on the results of the experiment, it was found that the effectiveness of epilam film directly depends on the cutting speed, which determines the temperature in the contact zone. Research has shown that use of oil-based LCTF MR-7 (MP-7) has the best effect on the state of epilam coating.

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1. INTRODUCTION

The working process of metal cutting involves the dynamic and kinematic interaction of two solids – the workpiece and the cutting tool [1]. When a cutting wedge is introduced into the material being processed, a plastic deformation of the cut layer is observed [2,3], chips are formed with the formation of new surfaces, in which the physic-mechanical properties of the near-surface layers are significantly different from the properties of the metal located in the depth of the workpiece. One of the sources of heat and the deformation factors of the near-surface layers during cutting is friction. With relative sliding of the contact surfaces of the tool and the workpiece under juvenile contact and the presence of plastic deformations, friction is accompanied by adhesive, adhesive-fatigue, adhesive-diffuse, chemical processes and to a large extent determines the state of the cutting tool, its durability and the quality of the processed surface. In the course of studies of the oil absorption of epilated, non-epilated and intermittently epilated surfaces, as well as the behavior of an oil drop on a hard surface, it was found that the greatest oil retention is observed with intermittent epilation, while it is located mainly in the absence of epilam in the form of large drops, the area of which, as a rule, depends on the area of unepilated areas [4-6].

This phenomenon is explained on the basis of the theory of wetting and spreading of a liquid drop on a solid surface: the behavior of a drop on wettable and non-wettable surfaces and at the interface between them is determined by the surface energy of a solid [7]. A drop on a metal has less potential energy than on an epilam, since $q^M < q^E$ (q^M и q^E – wetting angles of metal and epilam, respectively). Upon the transition of the wetting line from metal to epilam, the potential energy of

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the drop should increase. Therefore, the *M-E* boundary represents an energy barrier for moving the wetting line. On the contrary, the transition of the wetting line from epilam to metal occurs spontaneously, without the expense of external energy [8].

The behavior of the droplet on wettable and non-wettable surfaces and on the boundary between them is shown in Fig. 1 (arrows indicate surface tension forces). A drop located on the border of epilated and non-epilated surfaces tends to a surface with higher surface energy (metal). In this case, an increase in $\Delta q = q^E - q^M$ due to a decrease in q^M for metals with a higher surface energy at $q^E = const$ leads to an increase in the amount of lubricant held at the metal – epilam interface [9, 10].

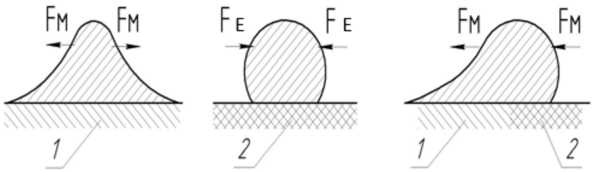


Fig. 1. Scheme of the behavior of a drop on a solid surface under various wetting: *1* – metal surface; *2* – epilated surface

One of the factors contributing to an increase in the wear resistance of epilated parts is the best lubricant retention by epilam coatings [11-15].

This phenomenon is explained on the basis of the theory of polymer adsorption from a solution proposed by F. Hesselink: when epilating, a layer of oriented surfactant molecules of surfactants (ПАВ) is formed, while the molecules form Langmuir structures in the form of spirals with axes normally directed to the surface of the material. This form of the molecule and its location can reliably hold lubricating media.

Fig. 2 shows the tails (indicated by the number 1), which are extended into space, and the loops (indicated by the number 2) holding the lubricant, while the polar part of the molecule is in direct contact with the solid surface [4,16,17].

The decrease in wear of parts with thin-film coatings is associated with a decrease in roughness and better protection of rubbing surfaces from oxidation and hydrogen penetration. According to experimental studies [18,19], the surface roughness during epilamation decreases by a factor of 2-2.5, which is associated with the filling of microdepressions and microroughnesses of the surface during epilamation with the epilam film (Fig. 3).

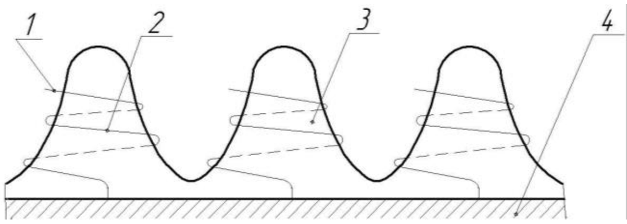


Fig. 2. A fragment of the Langmuir stockade on an epilated surface: *1* – tail of the surfactant molecule; *2* – loop surfactant molecule; *3* – lubricating medium; *4* – solid surface

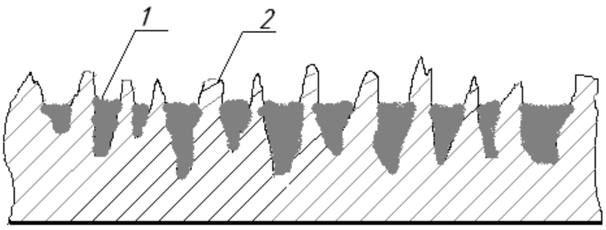


Fig. 3. A fragment of the surface of a solid body treated with epilam: *1* – epilam layer; *2* – solid surface

Thus, the task of the study is to establish the effect of epilam coatings on the process of friction and wear, as well as to investigate the condition of the surface layer of epilam drills.

2. MATERIALS AND METHODS

To study the mechanism of action of the epilam film during the operation of epilated drills and the influence of cutting conditions, processing conditions on their conditions, tribological tests were carried out using a special installation (Fig. 4), where the test conditions are close to the conditions characteristic of the drilling process.

For tribological studies, we used cylindrical specimens of Ø8.5 mm made of R6M5 (P6M5) high-speed steel (Fig. 5) on work surfaces that were coated with 6SFK (СФК) - 180-05 (SK) (СК) and Efren-2 (E2) compositions according to the technologies recommended by manufacturers these compositions, billets made of steel 45 (GOST 1050-2013) with holes (*Ra* = 1.6 µm). Testing of samples under various conditions was performed on a 2N125 (2H125) vertical-drilling machine using a setup (see Fig. 4), which allowed testing to be carried out under the conditions used in the production of this equipment.

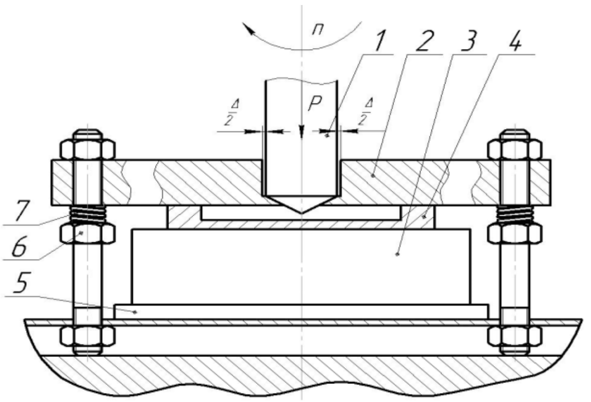


Fig. 4. Installation diagram for tribological testing of epilated samples: *1* – sample for testing; *2* – blank; *3* – dynamometer; *4* – a glass; *5* – plate; *6* – hairpin; *7* – spring

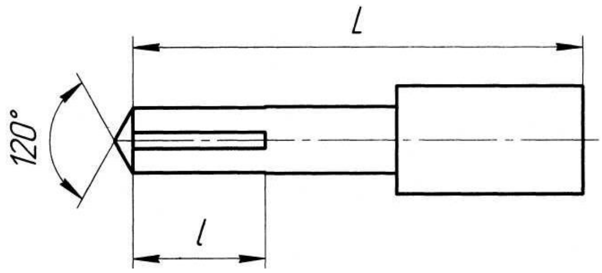


Fig. 5. Test specimen

The rotational speed of a cylindrical sample (n = 355 min^{-1}) corresponded to the theoretically permissible cutting speed v = 0.19 m/s, adjusted according to the passport data of a 2N125 (2H125) vertical drilling machine, as well as the closest values - 250, 500, 710 min^{-1}. The pressing force P of the epilated sample Ø8.5 mm to the surface of a blind hole in a steel plate was 500 N. Tribo tests were carried out with periodic withdrawal of samples from the friction zone, where the operating time was 15 s, the rest time was 10 s.

When performing the work, the following lubricant-cooling technological fluids (LCTF) of domestic production were used: MR-7 (MP-7) (TU 38. USSR20143-83), industrial oil I-40 (GOST 20799-88), sulfofresol, water-borne emulsol - Emolon-M (TU 0258-001-45939513-2003). The listed LCTF are used in drilling operations and are distinguished by the qualitative and quantitative content of anti-seize, anti-wear and antifriction additives.

Studies of the presence of a protective molecular film before and after work, depending on the time and used LCTF (oil MR-7 (MP-7), water-miscible Emolon-M), were carried out by the value of the contact angle *q* (Fig. 6) and the amount of oil retained on the working surfaces of the samples (oil absorption).

The assessment of the presence of a thin-film coating based on the contact angle *q* was carried out in the following sequence: on the surface of the samples, before and after tribo-testing, drops of MN-60 reference oil (GOST 8781-71) were applied with a calibrated scoop pad No. 6 (length of the working part A = 1.0$_{-0.10}$ mm). In this case, the values of the contact angles were determined for each drop using the universal measuring microscope (UMM) (УИМ) 23 (GOST 8074-82) and Axioscope (Karl Zeiss AG) microscopes, and the maximum and minimum values of the contact angles were discarded. The contact angle on the epilated surface should be between 35°-60°.

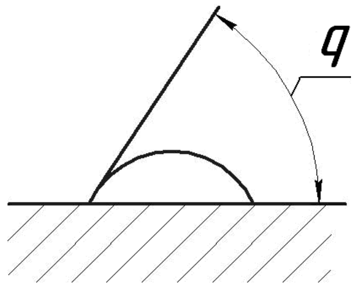


Fig. 6. Contact angle *q*

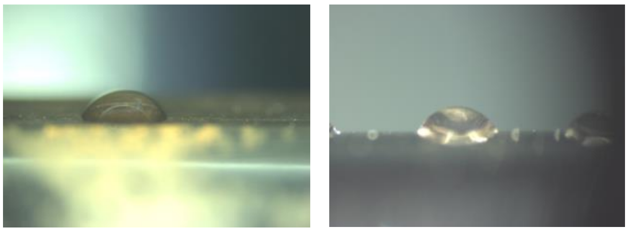
The presence of areas with different surface energies was determined by the amount of retained oil in the following order: all samples after work on the unit were weighed and placed in a bath with MN-60 reference oil in accordance with GOST 8781-71, then they were simultaneously removed and suspended vertically for a while until the oil drains off (24 hours) by gravity. After draining the oil, the samples were again weighed and the amount of oil held by a vertical surface was determined by the difference between the initial (before dipping into the bath) and final weight.

3. RESULTS AND DISCUSSION

After working at the installation for 2.5 min, the average value of the contact angle was: q_{E2} = 29°, $q_{СК}$ = 40°, $q_{E2+ЭМ}$ = 18°, $q_{СК+ЭМ}$ = 34°, $q_{E2+МР7}$ = 34°, $q_{СК+МР7}$ = 42°, which indicates a change in the state of epilam films. At the end point of the tests, oil spreading over the surface of the samples was observed, which corresponds to a *q* value of less than 5° and indicates the absence of a protective film.

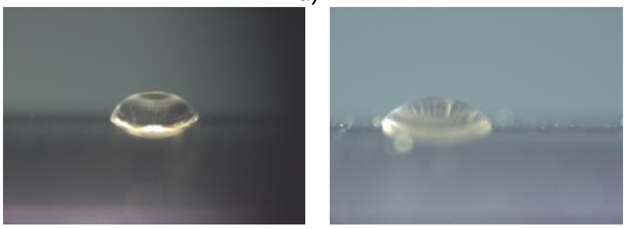
Fig. 7 shows photographs of an oil drop on the working surfaces of samples with 6SFK-180-05, Efren-2 thin-film coatings during processing without LCTF.

During previous production tests of epilated drills, it was noted [20] that the processing efficiency of a coated tool depends on the machining parameters, in particular, on the cutting speed *v*, m/s, which determines the temperature in the cutting zone and the temperature of thermal destruction of T_T coatings.



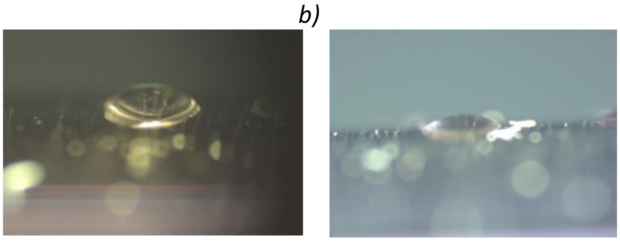
6SFK-180-05 *Efren-2*

a)



6SFK-180-05 *Efren-2*

b)



6SFK-180-05 *Efren-2*

c)

Fig. 7. Drops of oil on the working surfaces of samples working without LCTF: *a)* before work; *b)* 2.5 minutes of work; *c)* 5.5 min of work

To establish the dependence of the processing efficiency with an epilated tool on the drilling speed v, m/s and the temperature of thermal destruction of the *TT* coating, *ºC* under various processing conditions, i.e. without the use of LCTF, with the use of oil LCTF – MR-7 (MP-7) and water-mixed LCTF – Emolon-M, an experiment was planned taking into account these factors. The intervals of variation of the factors in the plan are given in Table 1.

In the range of variation of factors, the amount of retained oil *m* (g) is described by the following regression equations:

$$m = cv^{\alpha}T_T^{\ \beta}, \qquad (1)$$

where: *v* – is the cutting speed;

T_T – is the temperature of thermal destruction of the coating;

c, α, β – are the coefficients obtained experimentally (table 2).

Table 1. Intervals of variation of factors in the plan

Designation and dimension of factors	Range of variation	
	Upper limit	Lower limit
Drilling speed *v*, m/s	10.52	5.25
Thermal destruction temperature T_T, ºC	227	150

Table 2. The values of the regression coefficients of the model

Epilam brands	LCTF brands	Regression Equation Coefficients		
		c	*α*	*β*
6SFK-180-05	-	0.189	-0.1498	0.0494
Efren-2	-	0.023	-0.0355	-0.0694
6SFK-180-05	MP-7	0.027	0.0429	-0.0784
6SFK-180-05	Emolon-M	0.027	0.0116	-0.0699
Efren-2	MP-7	0.529	0.0233	-0.1567
Efren-2	Emolon-M	0.281	-0.0225	-0.0622

Mathematical models have been obtained to estimate the influence of technological factors and working conditions of epilated samples on the state of the coating.

The identification of patterns of changes in process quality indicators involves the construction of functional dependences of output parameters on factors:

$$\bar{Y} = F(\bar{x}), \qquad (2)$$

where: $\bar{Y}$ – is the assessment of the process quality indicator;

$\bar{x}$ – vector of technological factors.

Since it is not possible to obtain the analytical form of dependence (2) due to the complexity and multifactorial nature of the process, modeling was performed in the work.

Function (2) was represented as a second-order regression polynomial:

$$\bar{Y} = \bar{Q}\, f(\bar{x}) = \sum_{i=0}^{m} \sum_{j=0}^{m} Q_{ij} x_i x_j \,. \qquad (3)$$

where: $\bar{Q}$ – vector of unknown parameters of the regression model;

$\bar{x}$ – vector of technological factors of the test process;

$\bar{f}(\bar{x})$ – vector of model arguments of known functions of factors.

The first-order polynomial arguments are used as the model arguments.

To ensure the greatest accuracy of the model parameters and the greatest accuracy of the forecast of the output characteristic, the plans close to the D-optimal ones were used as factor plans for constructing regression models of the form (3). In some cases, plans were made on a computer to use the information obtained at the stage of preliminary experiments. The actual values of the factors in the plan were determined taking into account the conditions for the normal course of the process.

The variance of the reproducibility of the experiment was estimated by the formula:

$$s_{в}^{2}\{y\}=\frac{1}{n(N-1)}\sum_{i=0}^{m}\ \sum_{j=1}^{n}(y_{ji}-y_{i})^{2}, \tag{4}$$

where: y_{ji} – the value of the output characteristic in the j-th experiment of the i-series;
y_i – average value of the characteristic in the i-series;
n – the number of duplicate experiments in each series;
N – the number of series of experiments.

At each point in the factor space, a series of experiments was carried out, and the number of experiments in the series was chosen at least three.

The prerequisites of the regression analysis were checked by studying the homogeneity of the variances of reproducibility of experiments at different points of the factor space and the correspondence of the distribution of each output characteristic to a certain distribution law in accordance with the recommendations [21-24].

Building a regression model of the test process involves evaluating Q – parameters of the regression model and the choice of its arguments determined by the vector $\bar{f}(\bar{x})$.

$$\bar{Q}=(\bar{F}^{T}\ \bar{F})^{-1}(\bar{F}^{T}\ \bar{Y}) \tag{5}$$

where: $\bar{Q}$ – vector of model parameter estimates;
$\bar{Y}$ – vector of values of the output characteristic;

$$F=\begin{bmatrix} f_1(\bar{x}_1) & f_2(x_1). & \bar{.} & . & . & . & f_k(\bar{x}_1) \\ f_1(\bar{x}_2) & f_2(x_2). & \bar{.} & . & . & . & f_{k1}(\bar{x}_2) \\ . & . & & & & & . \\ . & . & & & & & . \\ f_3(\bar{x}_N) & f_2(x_N). & \bar{.} & . & . & . & f_k(\bar{x}_N) \end{bmatrix}$$ – matrix of model arguments;

k – number of evaluated parameters.

$S_{в}^{2}\{y\}\,(\bar{F}^{T}\ \bar{F})^{-1}$ – is a dispersion matrix of parameter estimates. Then estimates of the variances of the parameters can be determined by the diagonal elements of the dispersion matrix, and the significance of the estimates can be determined by the t-criterion.

$$t=\frac{|Q_i|}{\sqrt{S^{2}\{Q_i\}}}, \tag{6}$$

where: $|Q_i|$ – the modulus of the i-th parameter value;
$\sqrt{S^{2}\{Q_i\}}$ – variance estimation of the i-th parameter.

To select the arguments of the regression model, we used the step method. In the model, the argument most correlated with the output characteristic of the process was introduced at the beginning, and the model parameters were estimated. Then, the arguments of a possible set were introduced step by step with a uniform check of their significance and removal of insignificant arguments from the model.

The information content of the model was estimated using the dispersion relation:

$$F_{ин}=\frac{S^{2}\{y_{cp}\}}{S_{ост}^{2}\{\bar{y}\}} \tag{7}$$

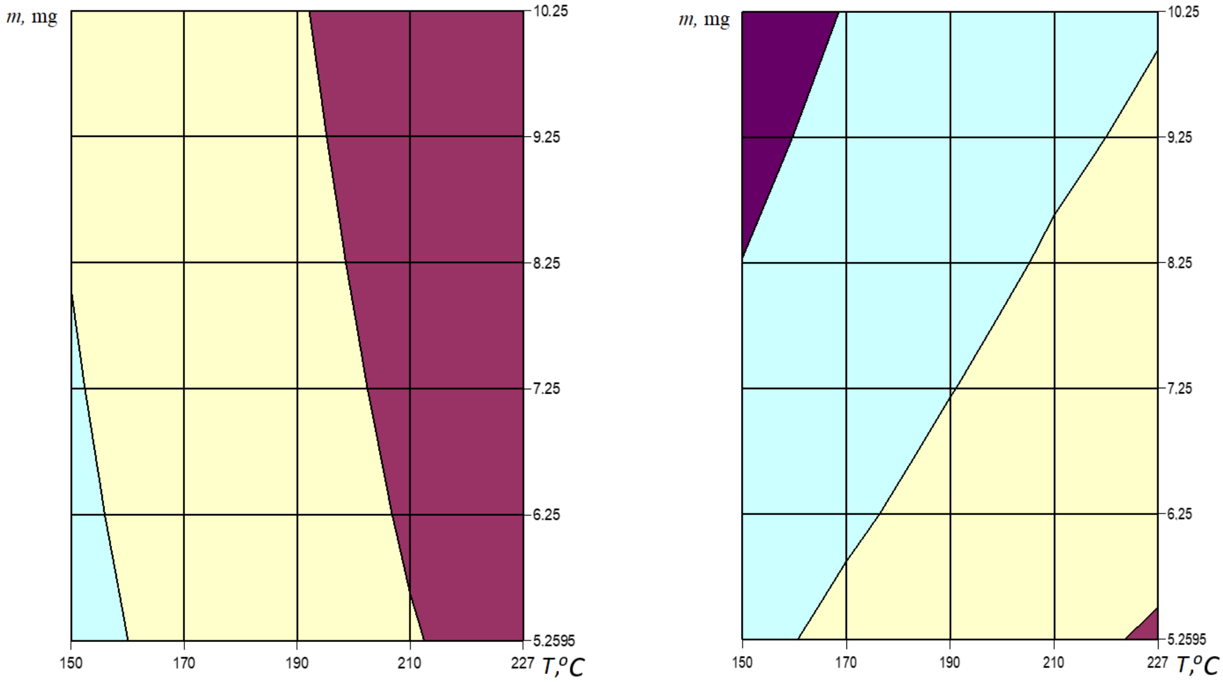
where: $S^{2}\{y_{cp}\}$ – dispersion of deviations of actual values y_i from their average value y_{cp};
$S_{ост}^{2}\{\bar{y}\}$ – residual variance of deviations of predicted values $\bar{y}_i$ from their actual values y_i.

The dispersion relation is used as a criterion for the adequacy of the regression model:

$$F_{ад}=\frac{S^{2}\{y_{cp}\}}{S_{ост}^{2}\{\bar{y}\}}. \tag{8}$$

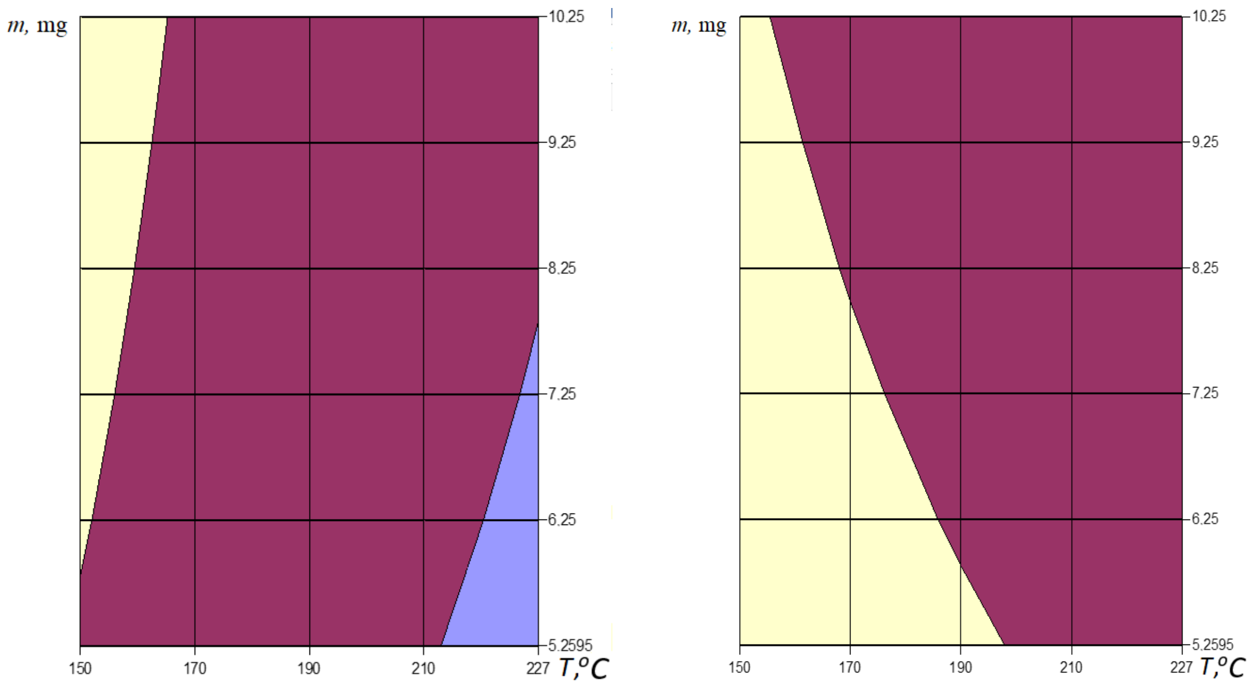
The higher the values of (8), the more reasonable is the assumption of the adequacy of the model. Processing of the results was carried out on an IBM PC.

Under equal operating conditions, samples coated with 6SFK-180-05 have better oil absorption performance than samples coated with Efren-2 (Fig. 8 and 9).



a) *b)*

Fig. 8. Dependence of the mass *m* of oil held by the working surfaces of the samples coated with 6SFK-180-05 *(a)* and Efren-2 *(b)* when working with MR-7



a) *b)*

Fig. 9. Dependence of the mass *m* of oil held by the working surfaces of the samples coated with 6SFK-180-05 *(a)* and Efren-2 *(b)* when working with Emolon-M

When working without the use of LCTF, an increase in temperature is observed in the contact zone, which negatively affects the state of the coating (Fig. 10).

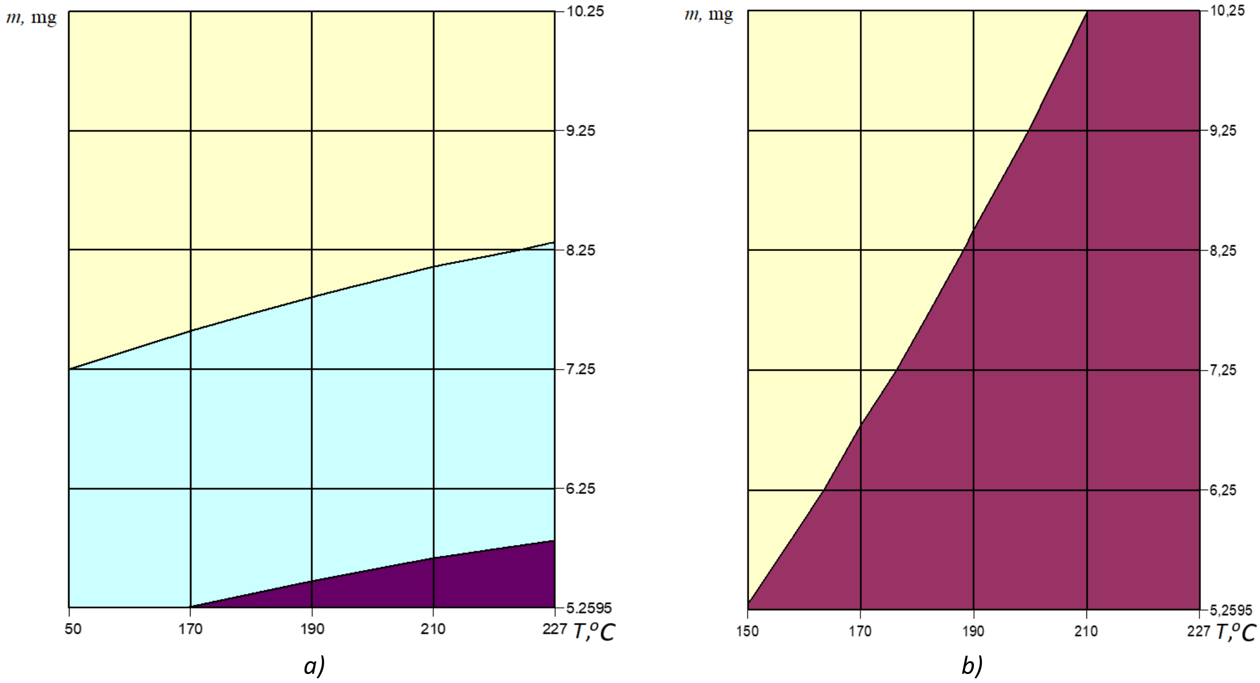


Fig. 10. Dependence of the mass *m* of oil held by the working surfaces of the samples coated with 6SFK-180-05 *(a)* and Efren-2 *(b)* when operating without the use of LCTF

4. CONCLUSION

Based on the results of experimental studies, it was found that the effectiveness of epilating directly depends on the cutting speed, which determines the temperature in the contact zone. The use of oil-based LCTF MR-7 (MP-7) has the best effect on the state of epilam coating, but this effect is ambiguous for different brands of epilam. The degree of influence depends on the temperature of thermal degradation of T_T epilam grades. For Efren-2 T_T is 150 ^oC, for 6SFK-180-05 TT – 227 ^oC.

When conducting research, LCTF with different operational properties was used: oil MR-7 (MP-7) and water-miscible Emolon-M. The studies were carried out with Efren-2 and 6SFK-180-05 coatings. Moreover, it was found that the use of oil LCTF is more effective.

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