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ESTABLISHING CHANGES IN THE PARAMETERS OF TEAT RUBBER FOR MILKING MACHINES DURING TESTING AND UNDER INDUSTRIAL CONDITIONS

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The teat rubber of milking machines is the only structural component of all milking and dairy equipment that is in contact with animals. During operation, the rubber article's original quality characteristics are compromised. This is due to mechanical wear during operation.

The task of the research is to establish changes in the parameters of the teat rubber of milking machines during testing and under industrial conditions. The object of research was the teat rubber of milking machines from various manufacturers, made of various composite materials.

A scientific hypothesis put forward assumed that an increase in the efficiency of milking and dairy equipment could be achieved by establishing changes in the parameters of the teat rubber with subsequent maintenance planning. This would provide an opportunity to identify patterns and dependences that characterize these processes.

In the course of research, theoretical dependences were derived to determine the operation of teat rubber in idle mode and the theoretical time of its operation. It was established that the theoretical wear period of the teat rubber is about 120–170 hours.

It was determined that in the environment of SZHR-3, the coefficient of aging in terms of intensity was >2 times higher compared to Skydrol LD-4. The volume under similar conditions of exposure of liquids on samples exceeded by more than 3 times. It is proved that the change in the mass of rubber under the influence of SZHR-3 exceeds more than 2.5 times the indicators obtained from the effects of Skydrol LD-4.

It was established that during long-term operation the teat rubber undergoes changes in its physical and mechanical properties. Thus, hardness and elasticity increase, elasticity decreases due to the destruction of the internal structure of rubber due to the formation of microcracks, the vacuum of closing the walls increases.

Knowledge of the quality characteristics of the teat rubber would make it possible to find the optimal solution for the choice of rubber articles

Keywords: teat rubber, rubber characteristic, rubber parameters, composite materials, rubber wear, closing vacuum

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1. Introduction

Dairy farms and plants use milking machines equipped with milking units, which perform the main function in the process of machine milking – the extraction of milk from the mammary gland of a cow. One of the main components of any milking machine that is in contact with the teats of the udder of the animal and whose influence affects milk yield is the teat rubber. Compared to the rest of the parts of the milking machine, its work takes place under adverse aggressive conditions. During milking, the rubber opens and compresses about 60–70 times per minute, and in 5–6 minutes it compresses the udder teat 300–420 times [1, 2].

The cow produces and gives milk as a result of the process of its suction (extraction) by the milking machine, which also involves physiological processes. How effective these processes will occur directly depends on the massage of teats and stimulation of the udder, which is carried out by the teat rubber [3].

The analysis of numerous experiments [4–6] testifies to the fact that the structural elements of the teat rubber significantly affect the characteristics of the milking process. Therefore, in order for the milking process to take place promptly and without causing damage to the animal, the rubber must comply with the technical and technological parameters.

Thus, the need for research is to establish changes in the parameters of the teat rubber of milking machines during testing and under industrial conditions. This is achieved by establishing changes in the properties of rubber articles in aggressive working fluids.

This approach could provide a real opportunity to reveal and expand the understanding of the qualitative technical and technological characteristics of rubber articles. This would lead to the rational use of milking machines and, therefore, could be of practical value.

2. Literature review and problem statement

The new teat rubber for teat cups has a high elasticity, plasticity, etc., which provide effective massage of udder teats, udder stimulation, and intensive milk excretion.

In [7], it is noted that during long-term operation, the teat rubber increases its length, changes its physical and mechanical properties while numerous small cracks form on the inner surface. These factors lead to an increase in bacterial fertilization of milk, a decrease in its quality, an increase in the likelihood of infection of the udder, and a decrease in the productivity of animals, which is emphasized in work [8]. Along with this, there is a decrease in the productivity of operators and milking machines, an increase in electricity costs for the technological process of milking, and early culling of animals. The result is a decrease in the profitability of the dairy cattle industry. According to a critical analysis of works [7, 8], it can be argued that there is insufficient disclosure of the issue of changes in the technical and technological properties of the teat rubber in the process of wear.

As shown in [9], the main parameters of teat rubber, which significantly affect the process of milking and animal health, are elasticity, plasticity, and elongation. However, there is no consensus on the rigidity of rubber articles. There are no uniform methods of defection and reliable data on the acquisition of teat rubber by stiffness groups in one milking machine have not been determined. It is difficult to judge the timing of the possible effective operation of the teat rubber since some authors give data on resource operation in hours [10], others in days [11].

Paper [12] indicates the problems that can be encountered with the wrong selection of teat rubber:

– air ingress during the connection of the suspension part and the milking process;

– crawling on the udder teat;

– lack of necessary massage of udder teats;

– increase in milking time;

– decrease in the completeness of milk yield;

– injury to the udder teat;

– the occurrence of teat swelling;

– deterioration of the health of the mammary gland.

Given the insufficient disclosure of this problem, it is required to establish changes in the parameters of the teat rubber of milking machines during testing.

Thus, milk producers operating milking and dairy equipment should have information on the milking machines' teat rubber and be guided by the basic principles of its selection and operation.

Previous studies on the operational technical and technological properties of rubber were carried out with a predetermined time of its wear. This excluded the possibility of reliable establishment of the main performance characteristics of new articles [13].

Studies of the issue of the functioning of milking and dairy equipment are reported in a number of works [14–16]. Thus, in [14], the issue of the influence of milking and dairy equipment on the properties of milk is considered. The authors of [15] revealed changes in the technical parameters of the teat rubber under industrial conditions while in [16] the state of the inner surface of rubber made of various materials was monitored.

But a number of issues related to the study of the technical and technological characteristics of the teat rubber of milking machines from various manufacturers remained unresolved. The reason for this is the costly part in terms of observations and the timing of the relevant research.

Therefore, it is expedient to carry out a study on the establishment of qualitative technical and technological characteristics of rubber articles.

3. The aim and objectives of the study

The aim of this study is to establish changes in the parameters of teat rubber during testing and under industrial conditions. This will make it possible to find an adequate solution in choosing rubber articles for milking a herd.

To accomplish the aim, the following tasks have been set:

– to theoretically investigate the wear of the milking machine's teat rubber during its operation;

– to establish the quality parameters and aging coefficient in terms of the intensity of the teat rubber of milking machines in aggressive working fluids;

– to determine the physical and mechanical properties of the teat rubber, which most fully characterize the effective life of the product.

4. The study materials and methods

According to the scientific hypothesis, increasing the efficiency of milking and dairy equipment can be achieved by establishing changes in the parameters of the teat rubber with subsequent maintenance planning. And also with the subsequent identification of patterns and dependences characterizing these processes.

The following samples of teat rubber were studied (Fig. 1).

The teat rubber was exposed to an aggressive solution of SZHR-3 at a temperature of 150 °C. In parallel, at a temperature of 150 °C, experimental rubber was kept in Skydrol LD-4 solution.

Fig. 1. Samples of teat rubbers submitted for research: *a* — rubber BARBAROS Liner 8S green from food grade silicone material (France) — sample No. 1; *b* — rubber IQ Pro elongated from food silicone material (Germany) — sample No. 2; *c* — rubber Melasty 3111 from material rubber (Turkey) — sample No. 3

The study of changes in the parameters of the teat rubber for milking machines during the test was carried out according to [17–19].

Measurements were carried out 3 times and we took the arithmetic mean of 3 readings. At the same time, permissible discrepancies did not exceed ±0.02 mm.

To determine the physical and mechanical properties of the teat rubber, a study was carried out in compliance with the necessary maintenance and without maintenance of the teat rubber operated at the Kutuzivka Research Farm in the Kharkiv oblast (Ukraine). Milking of cows at the farm involves the installation of the type «Christmas tree» produced by LLC «Bratslav» in the Vinnitsa oblast (Ukraine).

The study of the processes occurring in the teat rubber during its operation was carried out using the «Impulse-1P» installation (Fig. 2), which is used in industry to analyze the physical and mechanical properties of rubber materials.

Fig. 2. General view of the installation «Impulse-1P»

The installation includes an indentor mounted on a rotary lever, which, accelerating under the action of gravity, strikes the test material. A permanent magnet is attached to the indentor, which, while moving, directs an electro-propulsion signal in an inductance coil connected to the housing. Subsequently, this signal is amplified and through the synchronization unit enters the analog digital conversion unit. Then, through the serial port, it is transmitted to a personal computer for further processing and calculation of mechanical characteristics.

The effective service life of the teat rubber should be determined in the number of milkings. This is argued by the fact that the change in the properties of the teat rubber occurs only during the period of operation of the milking machine, and the operating time of the milking machine depends on the number of milkings per day. Also, this period depends on the number of milking machines in the milking plant and the number of livestock served.

The technology of maintenance of teat rubber during operation implied the following:

– without maintenance: disinfection; disassembly of milking machines (every 10 days); rubber washing; cleaning milking machines (every 10 days); circulating disinfection;

– with maintenance: disinfection; disassembly of milking machines (every 10 days); washing of teat rubber; rubber defection with testing for elasticity, plasticity, and grouping in groups for elasticity and plasticity (every 10 days); assembly of milking machines (every 10 days); circulating disinfection.

5. Results of establishing changes in the parameters of the teat rubber for milking machines during testing and under industrial conditions

5. 1. Theoretical studies of the wear of the milking machine's teat rubber during its operation

It is known that over time, the teat rubber is worn out. This is largely due to its constant pulsation during milking. As a result, its dynamic Young's modulus changes. The problem of the elastic state of homogeneous teat rubber operating in idle mode is solved (interaction with a teat is not taken into account). For the problem set, the deformation arising along the length of the teat rubber is taken into account. Its cross section is shown in Fig. 3.

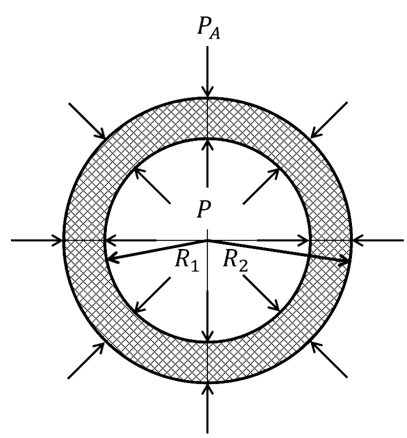

Fig. 3. Cross-section of the teat rubber

A constant vacuummetric pressure is applied to the inner surface of the teat rubber $r=R_1$:

$$\sigma_r\big|_{r=R_1} = P, \tag{1}$$

where R_1 is the internal radius of teat rubber, m, P – working pressure of vacuum system of milking equipment, Pa.

Atmospheric pressure occurs on the outer surface of the teat rubber $r = R_2$ during the compression stroke:

$$\sigma_r\big|_{r=R_2} = P_A, \tag{2}$$

where R_2 is the outer radius of the teat rubber, m, P_A is the atmospheric pressure, Pa.

To solve the problem, all stresses acting on the elementary area in polar coordinates are considered (Fig. 4).

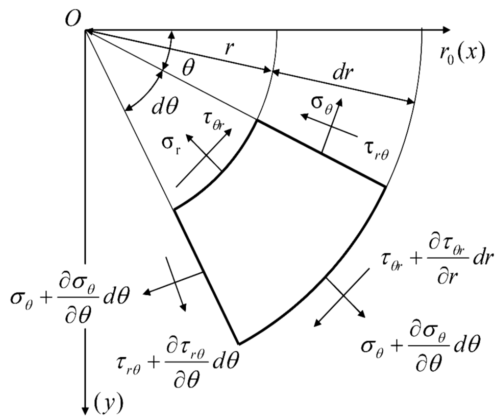

Fig. 4. Elementary area in polar coordinates

Equilibrium equations take the form:

$$\left.\begin{aligned}
&\left(\sigma_r + \frac{\partial\sigma_r}{\partial r}dr\right)(r+dr)d\theta - \sigma_r r d\theta - \\
&-\left(\sigma_\theta + \frac{\partial\sigma_\theta}{\partial\theta}d\theta\right)dr\sin\frac{d\theta}{2} - \sigma_\theta dr\sin\frac{d\theta}{2} + \\
&+\left(\tau_{r\theta} + \frac{\partial\tau_{r\theta}}{\partial\theta}d\theta\right)dr\cos\frac{d\theta}{2} - \tau_{r\theta}dr\cos\frac{d\theta}{2} = 0; \\
&\left(\sigma_\theta + \frac{\partial\sigma_\theta}{\partial\theta}d\theta\right)dr\cos\frac{d\theta}{2} - \sigma_\theta dr\cos\frac{d\theta}{2} + \\
&+\left(\tau_{\theta r} + \frac{\partial\tau_{\theta r}}{\partial r}dr\right)(r+dr)d\theta - \\
&-\tau_{\theta r} r d\theta + \left(\tau_{r\theta} + \frac{\partial\tau_{r\theta}}{\partial\theta}d\theta\right)dr\sin\frac{d\theta}{2} = 0,
\end{aligned}\right\} \tag{3}$$

where r and θ are the polar coordinates, σ_r, σ_θ are normal stresses, τ_r, τ_θ are tangent stresses.

Suppose that there is axial symmetry, that is, there is no angular displacement, and the radial u depends only on the radius r and time t. Given this, the system of equations (3) takes the form:

$$\left.\begin{aligned}
&\frac{\partial\sigma_r}{\partial r} + \frac{1}{r}\frac{\partial\tau_{r\theta}}{\partial\theta} + \frac{\sigma_r - \sigma_\theta}{r} = 0; \\
&\frac{\partial\tau_{r\theta}}{\partial r} + \frac{1}{r}\frac{\partial\sigma_\theta}{\partial\theta} + \frac{2\tau_{r\theta}}{r} = 0.
\end{aligned}\right\} \Rightarrow$$

$$\Rightarrow \frac{\partial\sigma_r}{\partial r} + \frac{\sigma_r - \sigma_\theta}{r} = 0 \Rightarrow \frac{d\sigma_r}{dr} = \frac{\sigma_\theta - \sigma_r}{r}. \tag{4}$$

Hooke's law for the problem set takes the form:

$$\begin{cases}
\varepsilon_r = 1/E\left[\sigma_r - \nu(\sigma_\theta + \sigma_z)\right], \\
\varepsilon_\theta = 1/E\left[\sigma_\theta - \nu(\sigma_r + \sigma_z)\right], \\
\varepsilon_z = 1/E\left[\sigma_z - \nu(\sigma_\theta + \sigma_r)\right],
\end{cases} \tag{5}$$

where E – Young's modulus of elasticity, kPa, ν – Poisson coefficient, ε_r, ε_θ, ε_z – relative deformations.

From the system of equations (5), we express σ_r and σ_θ:

$$\sigma_\theta = \frac{E}{2\nu^2 + \nu - 1}\left[\varepsilon_\theta(\nu - 1) - (\varepsilon_r + \varepsilon_z)\nu\right], \tag{6}$$

$$\sigma_r = \frac{E}{2\nu^2 + \nu - 1}\left[\varepsilon_r(\nu - 1) - (\varepsilon_\theta + \varepsilon_z)\nu\right]. \tag{7}$$

The following expressions for deformations are valid:

$$e_q = \frac{u(r)}{r},\ e_r = \frac{du(r)}{dr}. \tag{8}$$

Substituting (6) to (8) in (4), we obtain a second-order differential equation:

$$\frac{d^2u}{dr^2} + \frac{1}{r}\frac{du}{dr} - \frac{u}{r^2} = 0. \tag{9}$$

The solution to equation (9) is $u = Ar + B/r$. Substituting the resulting solution in (8) and (6), we have:

$$\sigma_\theta = \frac{E}{2\nu^2 + \nu - 1}\left[\left(A + \frac{B}{r^2}\right)(\nu - 1) - \left(\left(A - \frac{B}{r^2}\right) + \varepsilon_z\right)\nu\right], \tag{10}$$

$$\sigma_r = \frac{E}{2\nu^2 + \nu - 1}\left[\left(A - \frac{B}{r^2}\right)(\nu - 1) - \left(\left(A + \frac{B}{r^2}\right) + \varepsilon_z\right)\nu\right], \tag{11}$$

where A, B are the integration constants.

Taking into account the boundary conditions (1) and (2), we obtain the coefficients of integration:

$$B = \frac{1+\nu}{E}\frac{R_1^2 R_2^2 (P - P_A)}{R_1^2 - R_2^2}, \tag{12}$$

$$A = \frac{2\nu^2 + \nu - 1}{E}\frac{R_2^2 P_A - R_1^2 P}{R_1^2 - R_2^2} - \nu\varepsilon_z. \tag{13}$$

Substituting the expressions for A, B in (10) and (11), we finally have the stress:

$$\sigma_\theta = \frac{PR_1^2 - P_A R_2^2}{R_1^2 - R_2^2} - \frac{R_1^2 R_2^2 (P_A - P)}{R_1^2 - R_2^2}\frac{1}{r^2}, \tag{14}$$

$$\sigma_r = \frac{PR_1^2 - P_A R_2^2}{R_1^2 - R_2^2} + \frac{R_1^2 R_2^2 (P_A - P)}{R_1^2 - R_2^2}\frac{1}{r^2}, \tag{15}$$

$$\sigma_z = \nu(\sigma_r + \sigma_\theta) + E\varepsilon_z = 2\nu\frac{PR_1^2 - P_A R_2^2}{R_1^2 - R_2^2} + E\varepsilon_z. \tag{16}$$

Data on rubber aging obtained in [20] can be fitted to the exponential dependence of the dynamic Young's modulus:

$$E(t) = E_{di} + \left(E_{df} - E_{di}\right)e^{kt}, \tag{17}$$

where E_{di} and E_{df} are the initial and final values of the dynamic module, Pa, k is the constant of rubber wear rate, s^{-1}.

Given that the tension force of the teat rubber $F_H = \sigma_r S = \pi\sigma_r/2\left(R_2^2 - R_1^2\right)$, and substituting (16) in (17), we obtain:

$$\begin{aligned}
F_H &= \pi\nu\left(PR_1^2 - P_A R_2^2\right) - \\
&- \frac{\pi\varepsilon_z}{2}\left(R_2^2 - R_1^2\right)\left(E_{di} + \left(E_{df} - E_{di}\right)e^{kt}\right).
\end{aligned} \tag{18}$$

According to the structural parameters of the teat rubber ($P=52$ kPa, $P_A=102$ kPa, $\nu=0.75$, $\varepsilon_z=0.005-0.007$, $k=3.5\cdot10^{-3}-4.5\cdot10^{-3}$ h^{-1}, $R_1=0.011-0.015$ m, $R_2=0.018-0.023$ m, $E_{df}=18-25$ kPa, $E_{di}=8-10$ kPa), we obtain a dependence plot of the tension force of the teat rubber on the duration of its operation (Fig. 5).

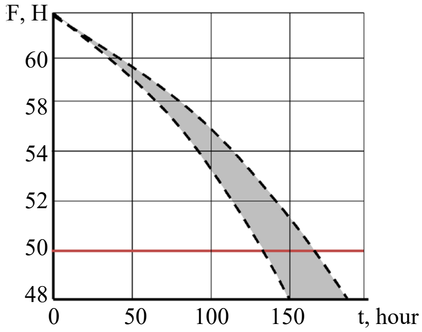

Fig. 5. Dependence plot of the tension force of the teat rubber on the duration of its operation

Taking into account zootechnical requirements (the tension force of the teat rubber should be in the range from 50 to 70 N) and Fig. 5, we obtain that the theoretical wear time of the teat rubber is about 120–170 hours. This is confirmed by the technical documentation (replacement of the teat rubber should be carried out every 160–180 hours of operation).

Table 1

Change in the technical and technological indicators of teat rubber after aging for 72 hours in the liquid environment at $t=150$ °C

Sample of rubber	Indicator	The value of the indicator for exposure in aggressive liquids	
		SZHR-3	Skydrol LD-4
No. 1	Mass, %	55.15	19.33
	Volume, %	67.65	21.75
	Relative final deformation, %	–50	31
	Coefficient of aging by intensity	0.81	0.41
No. 2	Mass, %	56.07	21.22
	Volume, %	68.47	22.14
	Relative final deformation, %	–58	36
	Coefficient of aging by intensity	0.82	0.42
No. 3	Mass, %	58.05	20.32
	Volume, %	85.55	27.16
	Relative final deformation, %	–74	45
	Coefficient of aging by intensity	0.73	0.36

5. 2. Investigation of qualitative parameters and aging coefficient in terms of the teat rubber stress

The analysis of research results (Table 1, Fig. 6, 7) revealed that the change in the mass of rubber of all 3 samples in 72 hours of exposure to the SZHR-3 liquid exceeds 2.5 times or more the indicators obtained by exposure to Skydrol LD-4 liquid. Thus, the specified indicator for sample 1 is 2.9 times; sample 2 – 2.6; and sample 3 – 2.9 times. As for the volume, under similar conditions of exposure to aggressive liquids on samples, this indicator exceeded more than 3 times. Thus, for samples 1 and 2 – 3.1 times, and sample 3 – 3.2 times.

In the environment of SZHR-3, the coefficient of aging by intensity ranged from 0.73 to 0.82. In the liquid Skydrol LD-4, this indicator ranged from 0.36 to 0.42. The obtained results testify to the fact that rubber articles have a wide variable range for this indicator. At the same time, the coefficient of aging in terms of intensity in the liquid SZHR-3 was less by 2 times compared to Skydrol LD-4 environment.

Regarding the final deformation due to swelling of the teat rubber samples, the indicator improves – the max value (45 %) for Skydrol LD-4 is in sample No. 3, and min (31 %) – in sample No. 1.

In the aggressive environment of SZHR-3, negative values were obtained for this indicator. Thus, the smallest value of the indicator (–74 %) was recorded in sample No. 3, and the largest (–50 %) – in sample No. 1.

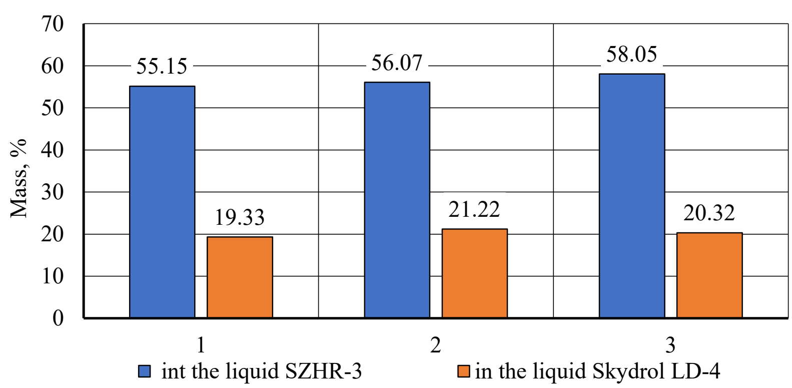

Fig. 6. Change in the mass of samples of teat rubber in an aggressive environment for 72 hours at $t=150$ °C: 1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3

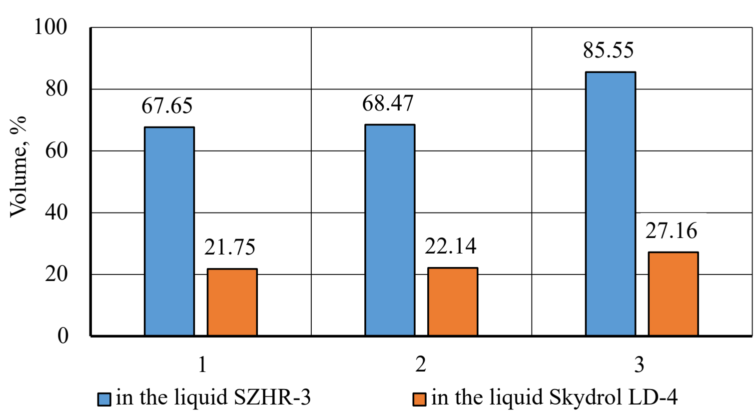

Fig. 7. Change in the volume of samples of teat rubber in an aggressive environment for 72 hours at $t=150$ °C: 1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3

The existing discrepancies in the results regarding a change in the mass of samples of teat rubber (Fig. 6, 7) in the aggressive environment of SZHR-3 (min=55.15 %; max=58.05 %) and the aggressive environment Skydrol LD-4 (min=19.33 %; max=21.22 %) are explained by different physicochemical parameters of the working fluids. Regarding a volume (min=67.65 %; max=85.55 %) and (min=21.75 %; max=27.16 %) in aggressive liquids of SZHR-3 and Skydrol LD-4, respectively, the obtained values are also explained by various physicochemical indicators of these liquids. In this case, the results obtained for all values for dependences coincide. This confirms their authenticity.

5. 3. Identification of the physical and mechanical properties of the teat rubber, which most fully characterize the effective life of the product

Studies have established that such technical and technological properties of teat rubber as hardness and elasticity increase over time (Fig. 8–10).

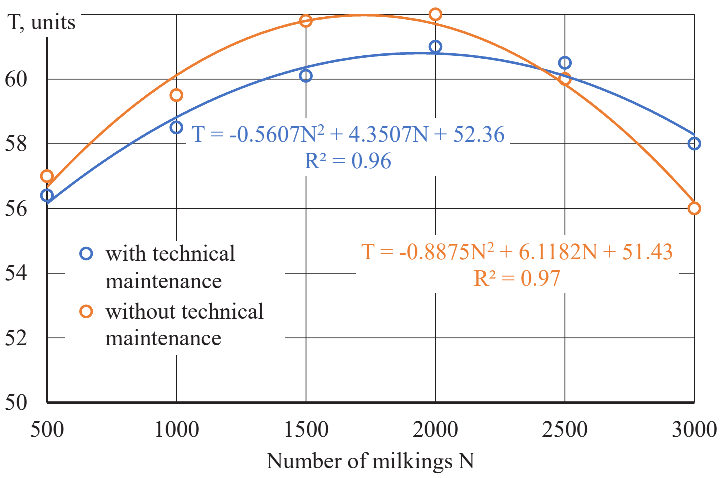

Fig. 8. Dynamics of changes in the hardness based on Shore of the teat rubber from the number of milkings with and without technical maintenance

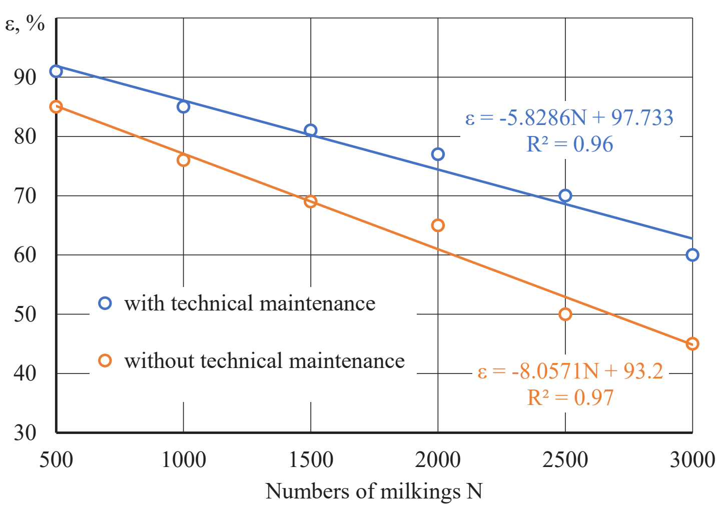

Fig. 9. Dynamics of changes in the elasticity of the teat rubber from the number of milkings with and without technical maintenance

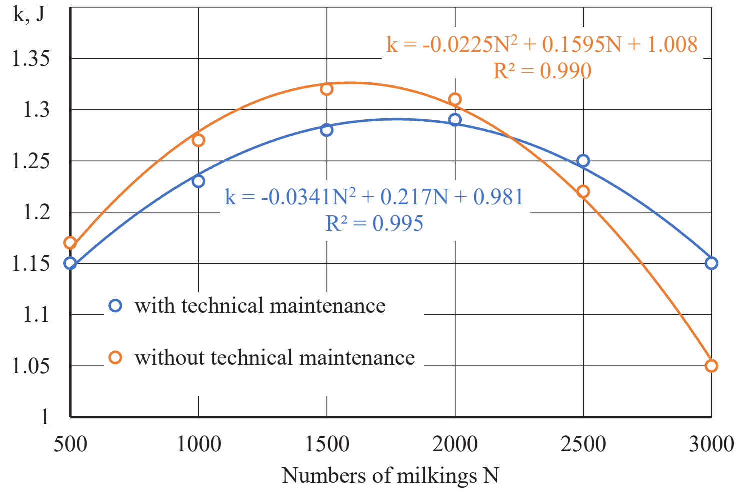

Fig. 10. Dynamics of changes in the elasticity of the teat rubber from the number of milkings with and without technical maintenance

These changes occur as a result of the destruction of the internal structure of the teat rubber since the increasing hardness leads to the «fragility» of rubber. As a result, microcracks are formed throughout the thickness of the material. The elasticity of the teat rubber is constantly decreasing and, after 1500 milkings (without maintenance), the drop in performance is accelerated. After 2000 milkings, elasticity and plasticity fall. It also confirms the formation of microcracks, due to which the rubber loses its ability to withstand elastic deformations.

The data obtained during the tests on the elongation and magnitude of the closure vacuum are described by polynomial dependences.

As for the lengthening of the teat rubber Δl (m):

– no maintenance:

$$\Delta l = 0.2647N + 17.938;\ R^2 = 0.8532; \quad (19)$$

– with maintenance:

$$\Delta l = 0.0109N^2 - 0.2197N + 21.107;$$
$$R^2 = 0.9778. \quad (20)$$

Regarding the value of the closing vacuum P (kPa):

– no maintenance:

$$P = 0.0108N^2 - 0.7878N + 90.222;$$
$$R^2 = 0.9929; \quad (21)$$

– with maintenance:

$$P = -0.3067N + 86.639;\ R^2 = 0.8898. \quad (22)$$

Investigating the regularities of the distribution of relative elongation and the magnitude of the vacuum of closing the teat rubber, it can be noted that they are nonlinear in nature.

6. Discussion of results of establishing changes in the parameters of the teat rubber of milking machines during testing and under industrial conditions

The rubber of teat cups is an intermediate element between animals and milking and dairy equipment. Therefore, extremely strict requirements are imposed on it. In order to withstand high levels of load and chemical exposure, a number of operational tests are carried out [21]. Thus, at the initial stage of research, the goal chosen goal was theoretical studies into the wear of the milking machine's teat rubber during its operation. Taking into account zootechnical requirements and Fig. 5, we found that the theoretical wear time of the teat rubber is about 120–170 hours.

At the next stage of research, the goal was to establish changes in the properties of the teat rubber for milking machines in aggressive liquids, such as SZHR-3 and Skydrol LD-4 (Table 1). Thus, changes in qualitative parameters in the liquid environment within 72 hours at t=150 °C were investigated (Fig. 6, 7).

It should be noted that testing the teat rubber according to known procedures is not reliable in terms of the measurements carried out and can be carried out only in limited conditions. This may not correspond to the operation of the rubber article. Along with this, the data obtained as a result of these tests may have an extremely large range of values. The complex reproducibility of the results according to such methods is due to the uneven thickness of the samples, large differences in its geometric values. Therefore, aggressive working fluids were used. This methodological approach is new in the study of rubber articles.

Our results regarding the establishment of quality parameters and the coefficient of aging by intensity in aggressive working fluids reveal the mechanism for changing the technical and technological parameters of rubber during operation. Given this, the problem of control over the process of milking is solved.

The teat rubber of milking cups is constantly exposed to destructive mechanical and physical factors [22]. Therefore, the purpose of further research was to determine the physical and mechanical properties of teat rubber, which most fully characterize the effective life of the product. Thus, the technical and technological properties of teat rubber, such as hardness, elasticity, and plasticity, were investigated (Fig. 8–10).

Our results of research regarding the establishment of changes in the parameters of the teat rubber of milking machines during testing and under industrial conditions are consistent with those reported by other authors carried out earlier [23–27] and complement them. A significant difference in the methodological plan of the research carried out was that it was possible to study a number of important technical and technological indicators (the coefficient of aging in terms of intensity, relative final deformation, etc.). But due to the significant variability of the parameters of rubber articles, there are difficulties in resolving the issue of existing shortcomings in their design.

The innovation of research is the introduction of procedures (study into the changes of the properties of teat rubber in aggressive working fluids) for the evaluation of rubber articles that are at the design stage. This will make it possible to resolve the issue of the optimal selection of materials for the manufacture of rubber.

Knowledge of the quality characteristics of teat rubber by domestic and foreign manufacturers will provide an opportunity to find the optimal solution for the choice of rubber articles. That will ensure an adequate stereotype of milking, the health of the udder of the animal, the operation of milking and dairy equipment, and the quality of milk.

The results of our research will be useful to agricultural workers engaged in dairy cattle breeding. And to manufacturers of milk rubber, manufacturers of milking and dairy equipment, as well as researchers involved in the design of milking equipment.

In the future, it is necessary to focus on the details of the teat rubber with a triangular cross-section where most changes in its physical and mechanical properties occur. This will make it possible to further eliminate existing shortcomings by improving and optimizing the design of the teat rubber.

7. Conclusions

1. Theoretical dependences have been derived to determine the wear of the teat rubber in idle mode and the theoretical time of its operation. It was established that the theoretical wear time of the teat rubber is about 120–170 hours.

2. It was found that in the environment of SZHR-3 the coefficient of aging in terms of intensity was >2 times higher compared to Skydrol LD-4. The volume under similar conditions of exposure of liquids on samples exceeded more than 3 times. The change in the mass of rubber under the influence of SZHR-3 exceeds more than 2.5 times the indicators obtained from the effects of Skydrol LD-4.

3. During long-term operation, changes in the physical and mechanical properties occur in the teat rubber. This increases hardness and elasticity, reduces plasticity because of the destruction of the internal structure of rubber due to the formation of microcracks; there is an increase in the vacuum of closing the walls.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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