Дійкова гума – важлива частина доїльного апарату, один з його ключових елементів. Це той єдиний компонент доїльної установки, який має безпосередній контакт з поверхнею вимені корів. Поряд з цим, дійкова гума – це самий навантажений компонент доїльного апарату. За час процесу доїння вона стискається і розтискається понад 400 разів. З метою максимального ефекту від використання дійкової гуми, необхідно правильно розрахувати умови її використання, своєчасно здійснювати контроль технічних параметрів. Завдання дослідження полягає у встановленні змін технічних параметрів дійкової гуми доїльних апаратів та їх впливу на експлуатаційні характеристики виробу.

В ході досліджень встановлено, що працездатність всіх дійкових гум склала 1000 годин, що при напрацюванні в день восьми годин відповідає 125 дням або 4 місяцям експлуатації. При напрацюванні в 1000 годин жорсткість дійкової гуми коливається в значних межах і в середньому становить: для виробів з силікону 2849,61±52,23–3343,76±51,26 Н/м; з матеріалу гумових сумішей – 2597,76±78,26–2821,43±55,24 Н/м. Коефіцієнт готовності усіх виробів становить 1. За використання електронної мікроскопії встановлено зміни внутрішньої поверхні дійкової гуми після напрацювання 125 днів/1000 годин та після експлуатації протягом 250 днів/2000 годин. Доведено, що змінам під час експлуатації дійкової гуми піддаються всі основні її параметри. Маса виробу змінюється на 8,5 %, глибина – на 37 %, товщина стінок – 2,5 %, а довжина розтягнення – на 27 %. Між жорсткістю дійкової гуми та інтенсивністю молоковіддачі встановлено високу позитивну кореляційну залежність (r=+0,939).

Досліджені показники є важливими у визначенні працездатності та придатності дійкової гуми до використання. Проведені дослідження представляють реальну можливість врахування якісних параметрів дійкової гуми доїльних апаратів під час вибору та подальшої експлуатації

Ключові слова: дійкова гума, доїльний апарат, доїльний стакан, контроль параметрів гуми, експлуатація дійкової гуми

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ESTABLISHING CHANGES IN THE TECHNICAL PARAMETERS OF NIPPLE RUBBER FOR MILKING MACHINES AND THEIR IMPACT ON OPERATIONAL CHARACTERISTICS

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1. Introduction

Machine milking is one of the most complex production processes at a dairy complex. The effectiveness of its use depends on many factors associated with the physiological state of an animal. The share of this process accounts for about 50 % of the total labor costs of a dairy herd servicing. Unlike manual milking, machine milking facilitates and simplifies the work of operators and increases performance by several times [1, 2].

Modern milking equipment during operation should promote the realization of a full-fledged milking process of cows, exclude the possibility of blood circulatory disorders, ensure natural parameters of the magnitude of vacuum and take into consideration individual characteristics of an animal [3].

The quality of milking cups is of particular importance [4]. Its wear occurs due to the negative impact of water, milk fat, detergents, sunlight, changes in temperature. Because of these factors, nipple rubber loses its elasticity, there occur microcracks that badly injure the udder nipples during milking. A cow during the milking process feels pain, which inhibits milk giving and, consequently, the time of milking increases.

The technical characteristics of nipple rubber are the factors that determine the character of rubber operation during milking, and, consequently, its effect on the animal organism. Therefore, the rubber article of a milking cup should be given due attention. Thus, the need to study the operational characteristics of nipple rubber implies the need to establish the changes in its technical parameters that occur during its being used under production conditions. This is achieved by the establishment of work efficiency of nipple rubber of various manufacturers after 125 days/1,000 hours of operation with subsequent studying the inner surface of nipple rubber using electron microscopy.

This approach will make it possible to expand the idea of the mechanism of changes in nipple rubber occurring in the process of its operation and will lead to the rational use of rubber articles of milking machines, therefore, will bring practical benefits. Thus, the research of this kind is relevant.

2. Literature review and problem statement

The analysis [5, 6] in the field of dairy farming has shown that a decrease in the losses of cows' milk productivity and an increase in the quality of obtained milk depend on numerous factors. These include the motor function of the breast, advanced and normed feeding, reproduction of animals for many years of operation under the conditions of industrial complexes, prevention and early diagnosis of mastitis, improvement of the technology of machine milking, etc. However, the biggest milk losses (≈50 %) are caused by technical reasons because the design and operating modes of milking machines fail to meet the physiological needs of animals [7].

The main tasks in the development of mechanisms of milking are the elimination of structural shortcomings and causes, leading to the inhibition of milk yield, achievement of a reliable interaction of an executive mechanism and an animal, ensuring the simplicity and operational reliability of a structure [8]. Thus, paper [9] emphasizes the need for a more detailed review of the features of nipple rubber operation – the most important executive mechanism of a milking plant, which directly interacts with the animal's body. It is this element that is in direct contact with a cow's udder nipple. During milking, nipple rubber is designed to protect the nipple from the effect of a high vacuum and restore the normal blood circulation in it. In fact, during compression tact, the rubber has a traumatic action, flattening in the form of a slit and deforming an udder nipple in one plane. In this case, the nipple tip acquires a bilateral flattened appearance, the sphincter is pressed and opens passively, exposing the nipple and the inner cavity of the udder to the action of deep vacuum [10].

The study [11] in the field of flexible shells, which include nipple rubber, reveals the mechanism of phenomena occurring in the compression cycle. As soon as the atmospheric air begins to fill the interwall space of a milking cup, the rubber loses its shape and becomes flattened in the shape of an eight or an ellipse in the transverse direction.

To determine the degree of significance of the factors affecting the nature of the movement of the wall of nipple rubber, the mathematical model of the process of nipple rubber compression was developed and explored [12]. It was established that the degree of influence of the structural and physical-mechanical parameters within the limits that meet the physiological needs of animals is insignificant.

The studies [13] revealed that during using worn-out nipple rubber, 5 % of milk yield is lost. This leads to incomplete milking of a cow, resulting in a loss of up to 12 % of milk fat and significant damage to the animal's overall health.

According to research [14], the magnitude of pressure on the end of the udder nipple depends mainly on the following factors: the thickness and stiffness of nipple rubber, the magnitude of its tension in a milking cup, and working vacuum.

Previously conducted research into the operational properties of nipple rubber was carried out with the preknown time of their operation, which excluded the possibility of establishing the changes in parameters during its phased operation period. In addition, based on these studies, it was difficult to make a comprehensive assessment of the duration of using nipple rubber [15].

The material from which nipple rubber is made is predominantly a rubber mixture. At the same time, the use of silicone articles with many advantages is considered to be the most effective nowadays [16]. Silicone rubber first appeared in the market in 1944 and since then it has been increasingly used in everyday life, particularly in the food industry.

Papers [17, 18] focus on the issue of milking equipment functioning. They emphasize the functioning of the separate elements of milking plants, their impact on the technological process of milking. Thus, the pulse characteristics of nipple rubber and calculated data of pulsors' operation were outlined theoretically and the performance of a manipulator was presented as a narration. However, the issues, related to the research into performance characteristics of nipple rubber made from different materials directly in production conditions, remain unresolved. The reason for this is objective difficulties associated with the access to dairy complexes, fundamental inability to manipulate the milking herd, the expenditure part as for the terms of the relevant research and observations.

It can be argued that it is advisable to research the establishment of changes in the technical parameters of the nipple rubber of milking machines that are observed during operation.

3. The aim and objectives of the study

The aim of this study is to establish the changes in the technical parameters of nipple rubber for milking machines and their impact on the operational characteristics of this product.

To achieve the set aim, the following tasks should be solved:

– to establish experimentally the workability of nipple rubber of various manufacturers after operating for 125 days/1,000 hours and to prove their suitability for use;

– to explore the inner surface of nipple rubber using electron microscopy;

– to determine the patterns of changes in the technical parameters of nipple rubber and to establish the nature of their influence.

4. Materials and methods to study the technical parameters of nipple rubber for milking machines

4. 1. Procedure for studying the workability of nipple rubber by various manufacturers

The experiment was carried out at the State enterprise «Experimental farm «Gontarivka» in the Vovchansk district of Kharkiv oblast (Ukraine) at the tied keeping of dairy cows of the Ukrainian black-spotted milking breed. The animals are milked into the milk pipeline.

The average milk yield was 6,750 kg during preliminary lactation. The average fat content of milk was 3.8 %.

The water used to wash the system was at t=40–45 °C and had a general stiffness of 6.4 mol/m^3.

According to the procedure [19], we maintained the conditions of sampling and conducted an initial examination of articles, established the suitability for tests, found faulty rubber. We followed the algorithm for testing nipple rubber, used the approaches and manipulations that are necessary during the test works. In particular, we measured the elastic properties of rubber in order to determine its stiffness by absolute extension at the applied load of 58.86 N for 10 s. Stiffness of nipple rubber under the load of 58.86 N was determined according to [20].

As the magnitude that is directly proportional to the module, stiffness is a material characteristic of a rubber article and has its calculated value. Eq. (1) makes it possible to find stiffness C experimentally.

$$C=\frac{P}{\Delta l}, \qquad (1)$$

where C is the stiffness of nipple rubber, P is the pressure by the load of 58.86 N, Δl is the total stretching, mm.

The study presented:

– 10 pieces of rubber DD.00.041A from silicone produced by VAT «EuroAgroTech», the city of Krasnodar (Russia) – No. 1;

– 10 pieces of rubber DD.00.041A from silicone FSI-55P produced by AT «Stoimash», the city of Cheboksary (Chuvash Republic) – No. 2;

– 10 pieces of rubber DD.00.041A from the material of rubber mixtures produced by AO «Bratslav» the settlement of Bratslav, Nemirov district of Vinnytsia oblast (Ukraine) – No. 3;

– 10 pieces of rubber DD 00.041A from the material of rubber mixtures produced by BAT «Rezinotechnika», the town of Borysove (Belorus) – No. 4.

The represented samples were made based on silicone and rubber mixtures (Fig. 1).

Rubber is a single part with a milk nozzle and has three locking ring grooves, which makes it possible to pull it in a milking cup as it is stretched during the operation.

At the initial stage, using the geometric measurements, it was established that all the presented articles fully comply with all the technical specifications [21] (Table 1).

The lack of data on technical conditions [21] (in Table 1 (–)) is explained by a wide variability of the above indicators, which is proved in article [18].

The parameters of nipple rubber, which were subjected to measurement during the research, are shown in Fig. 2.

Thus, the length of the operating part of the article, the diameter of the suction cup and the inner diameter of the tail part of the nipple rubber were measured according to the scheme in Fig. 2.

Fig. 1. Nipple rubber represented in the study: *a* – nipple rubber of brand DD.00.041A from silicone (food silicone); *b* – nipple rubber of brand DD.00.041A from silicone FCI-55P (food silicone); *c* – nipple rubber of brand DD.00.041A from the material of rubber mixtures (black rubber); *d* – nipple rubber of brand DD.00.041A from the material of rubber mixtures (black rubber)

To conduct research, 2 milking machines were equipped with nipple rubber No. 1 from food silicone, as well as 2 milking machines were equipped with nipple rubber No. 2 from silicone FCI-55P, 2 milking machines – with nipple rubber No. 3 and 2 milking machines – with rubber article No. 4. The remaining rubber was left as spare parts.

Reliability indicators of rubber elements were determined by lengthy multiple tests of their small quantity and statistical processing of test results. The readiness coefficient (Kg) of the samples of nipple rubber was determined from formula (2).

$$Kg=\frac{Ns(t)}{Nt(t)}, \qquad (2)$$

where $Ns(t)$ is the number of serviceable rubber elements at moment of time, $Nt(t)$ is the total number of elements.

The research materials were processed and analyzed with the help of the standard package of licensed applied statistical application SPSS – 12.0.

The correlating dependence was found by a correlation coefficient of Pierson r, which is a dimensionless index in the range from – 1.0 to 1.0 inclusively and reflected the measure of linear dependence between two datasets.

The research results were processed by the method of variation statistics based on calculating the arithmetic mean, deviation of indices from the arithmetic mean error and reliability of the difference between the comparable indicators.

Table 1

Technical characteristic of the nipple rubber presented in the research

Indicator	Value of indicator				
	Technical conditions	Data from studying the rubber			
		No. 1*[1]	No. 2*[2]	No. 3*[3]	No. 4*[4]
Vacuum metric pressure, kPa	48±1	48	48	48	48
Pulsation frequency, pulse/min	65±3	61.2	62.4	62.8	63.1
Ratio of cycles, %: sucking; compression	 60±3 40±3	 61.2 39.4	 62.8 38.1	 62.4 38.2	 62.7 38.7
Weight of one article, g	107	97	100	102	103
Length of a milking cup, mm	–	159	159	159	159
Length of a milking cup in assembly with rubber, mm	–	307	307	308	308
Length of milking rubber, mm	–	288	288	292	294
Outer diameter of a milking cup, mm	–	41	41	41	41
Inner diameter of a milking cup, mm	–	37	37	37	37
Geometrical dimensions, mm: length of operating part; diameter of sucking device opening	 152 25.0	 149.8–150.1 25.0–25.3	 149.7–150.3 24.8–25.1	 153.1–155.0 25.3–25.6	 153.1–154.8 25.4–25.6
Outer diameter of tail part	9.0	8.8–9.1	8.8–8.9	8.9–9.1	9.0–9.1
Outer diameter of sucking device	60.0	60.0	60.0	60.0	60.0
Inner diameter of sucking device	27.6	27.6	27.6	27.6	27.6
thickness of walls	2.2	2.2	2.2	2.2	2.2
Stiffness of nipple rubber, N/m	–	3,120.46±55.19	3,435.39±64.21	2,842.36±72.23	2,759.77±75.16

*Note: *[1] – nipple rubber of brand DD.00.041A from silicone (food silicone); *[2] – nipple rubber of brand DD.00.041A from silicone FCI-55P (food silicone); *[3] – nipple rubber of brand DD.00.041A from the material of rubber mixtures (black rubber); *[4] – nipple rubber of brand DD.00.041A from the material of rubber mixtures (black rubber)*

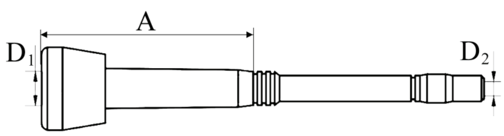


Fig. 2. Schematic of control over the geometric parameters of nipple rubber: *A* — length of operating part of the article; D_1 — diameter of the suction device opening; D_2 — inner diameter of the tail part of nipple rubber

4. 2. Procedure for studying the inner surface of nipple rubber with the use of electron microscopy

To study the inner surface of nipple rubber, we used raster electron microscope REM-106 produced by VAT «SELMI», the city of Sumy, Ukraine. It is a stationary automated multi-function measuring system. The principle of obtaining the image of REM-106 is to modulate the brightness of the monitor of a video control device by the signals, proportional to the number of registered secondary electrons when scanning a focused electronic probe on the surface of an object. The ratio of the image size on the monitor to the raster dimensions on the sample is determined by the microscope multiplication.

The functions of measuring the linear dimensions of objects were performed and the quality composition of the object was determined using the method of X-ray microanalysis.

Basic features of the technical device are the following:

– level of resolution in high-level vacuum mode is 4 nm;

– level of resolution in low-level vacuum mode is 6 nm;

– the value of maximum image size is at the level of 1,280×960 pixels;

– parameters of pressure regulation range inside the chamber is from 1 Pa to 270 Pa;

– parameters of ranges of voltages of accelerating type are from 0.5 kV to 30 kV;

– parameters of multiplication ranges are from 15 to 300,000;

– parameters of a range of measurements of dimensions of linear character are from 0.2 to 5,000 µm.

According to the procedure [22], the studied objects had the appropriate dimensions, limited from the top by the dimensions of the operating chamber gateway and were resistant to irradiation with a beam of electrons with a dose of about 10^3 µmKl/cm^2. The rubber samples were stable and did not evaporate at the pressure of 10^{-4} Pa. The specific resistance of the sample material did not exceed the magnitude of 10^4 Ohm/cm.

4. 3. Procedure for studying the patterns of changes in the technical parameters of nipple rubber and for establishing the nature of their influence

The technical state of nipple rubber was assessed during its installation in the machine and every two months of operation after washing and daily «rest». Stretching of special rubber under the influence of the standard load was measured with the help of the technical and technological solutions [20].

In order to determine the performance properties of nipple rubber, the following measures were taken:

– the rubber was washed in the solution of detergents with the application of brush;

– the rubber was disinfected and washed;

– the rubber was placed on the shelf and kept for 10 days to restore its shape and size;

– the visual examination of the rubber state was performed to detect defects (cracks, deformations, and changes in the shape of openings);

– the length of the rubber was checked and cut off if necessary;

– rubber was arranged according to stiffness.

The weight of nipple rubber was determined using the analytical electronic scales AS 60/C with the liquid crystal indicator that was entered in the State Register of Ukraine with No. Y 1821-09.

The length of nipple rubber was based using a ruler on a tripod: from the base of the sucker to the bottom edge of the third from the sucker of the ring deepening in the place of transition of a sucking part of rubber to the milk pipe.

The average intensity of milk yield (Q) in kg/min was calculated from formula (3).

$$Q=\frac{\sum(q_1+q_2)}{\sum(t_1+t_2)}, \quad (3)$$

where q_1 is the magnitude of machine milking, kg, q_2 is the magnitude of machine additional milking, kg, t_1 is the duration of machine milking, min, t_2 is the duration of machine additional milking, min.

5. Results of studying the technical parameters of nipple rubber for milking machines

5. 1. Studying the workability of nipple rubber for milking machines

During the examination of the mechanism of operation of nipple rubber, it should be noted that the milking process will occur in more favorable and stress-free situations for animals if we pay due attention to the factors that influence the milk yield of cows and their health. And such factors, first of all, include the operational characteristics of rubber, on which its performance depends.

To investigate the performance of nipple rubber of milking machines after their operation for 125 days/1,000 hours, the articles were subjected to measurement of geometric parameters and the magnitude of closing vacuum. Research results are shown in Tables 2–5.

After the operation for 125 days/1,000 hours, the studied samples had the following magnitudes: the length of the operating part of article (A) No. 1 was 150.1–150.4 mm; of article No. 2 – 150.1–150.4 mm; of nipple rubber No. 3 – 154.5–156.0 mm; of rubber No. 4 – 154.5–155.4 mm. The diameter of sucking opening (D_1) had the value: of article No. 1 – 25.1–25.3 mm; of nipple rubber No. 2 – 24.9–25.2 mm; of article No. 3 – 25.5–25.7 mm; of rubber article No. 4 – 25.6–25.8 mm. The inner diameter of the tail part of nipple rubber (D_2) was: of article No.1 – 9.0–9.2 mm; of nipple rubber No. 2 – 8.8–9.0 mm; of article No. 3 – 9.0–9.4 mm; of rubber article No. 4 – 8.9–9.4 mm. In this case, the stiffness of rubber articles had the following values: of article No. 1 – 3,119.46±55.16–2,849.61±52.23 N/m; of nipple rubber No. 2 – 3,343.76±51.26–3,137.71±35.18 N/m; of article No. 3 – 2,821.43±55.24–2,719.93±66.27 N/m; of rubber article No. 4 – 2,751.67±75.16–2,597.76±78.26 N/m.

The output parameters of the stiffness of nipple rubber were the data given in Table 1. Thus, after the operation for 125 days/1,000 hours, the stiffness of nipple rubber No. 1 decreased by 1.1 times. Rubber No. 2 was subjected to the same changes in stiffness (decrease by 1.1 times). Along with this, the stiffness of the samples of rubber articles No. 3 and 4 changed within the insignificant limits.

Table 2

Parameters of nipple rubber No. 1 after the operation for 125 days/1,000 hours

No. of article	Geometric dimensions, mm			Stiffness of nipple rubber, N/m	Ovality of cross-section, %
	A	D_1	D_2		
1	150.4	25.3	9.0	3,119.46±55.16	2
2	150.2	25.2	9.2	2,849.61±52.23	4
3	150.1	25.1	9.2	2,967.36±65.19	3
4	150.1	25.2	9.1	3,018.39±75.12	5
5	150.2	25.1	9.1	3,019.76±49.27	1
6	150.3	25.1	9.1	2,988.83±65.22	2
7	150.2	25.2	9.2	2,899.37±55.41	4
8	150.2	25.2	9.1	3,022.31±85.13	3

Note: $P<0.05$

Table 3

Parameters of nipple rubber No. 2 after the operation for 125 days/1,000 hours

No. of article	Geometric dimensions, mm			Stiffness of nipple rubber, N/m	Ovality of cross-section, %
	A	D_1	D_2		
1	150.4	25.0	8.8	3,218.58±49.19	2
2	150.4	24.9	8.8	3,343.76±51.26	3
3	150.1	24.9	8.9	3,137.71±35.18	1
4	150.2	25.0	9.0	3,229.74±65.22	4
5	150.3	25.0	9.0	3,176.21±71.36	5
6	150.2	25.2	8.9	3,239.46±61.16	6
7	150.2	25.0	8.9	3,319.33±75.24	2
8	150.3	25.0	8.9	3,249.49±59.46	3

Note: $P<0.05$

Table 4

Parameters of nipple rubber No. 3 after the operation for 125 days/1,000 hours

No. of article	Geometric dimensions, mm			Stiffness of nipple rubber, N/m	Ovality of cross-section, %
	A	D_1	D_2		
1	154.5	25.5	9.0	2,769.35±45.39	2
2	156.0	25.5	9.0	2,811.28±69.19	3
3	155.0	25.7	9.1	2,777.43±65.31	1
4	155.0	25.7	9.3	2,789.22±85.14	4
5	155.4	25.6	9.4	2,821.43±55.24	2
6	155.6	25.7	9.2	2,793.53±75.31	3
7	155.0	25.6	9.2	2,719.93±66.27	2
8	155.2	25.7	9.3	2,819.31±59.33	3

Note: $P<0.05$

Table 5

Parameters of nipple rubber No. 4 after the operation for 125 days/1,000 hours

No. of article	Geometric dimensions, mm			Stiffness of nipple rubber, N/m	Ovality of cross-section, %
	A	D_1	D_2		
1	154.6	25.6	9.2	2,750.43±65.32	2
2	154.8	25.6	9.1	2,699.31±74.43	2
3	155.0	25.6	8.9	2,685.71±64.25	1
4	154.5	25.7	9.3	2,597.76±78.26	4
5	155.4	25.7	9.4	2,684.73±66.32	5
6	155.2	25.6	9.4	2,671.39±45.24	3
7	155.0	25.6	9.2	2,684.81±55.31	2
8	155.2	25.8	9.3	2,751.67±75.16	2

Note: $P<0.05$

After the operation for 125 days/1,000 hours of nipple rubber, its ovality of intersection also changed: by 1–4 % (on average 3 by %) of article No. 1; by 1–6 % (on average by 3.3 %) of rubber article No. 2; by 1–4 % (on average by 2.5 %) of article No. 3 and by 1–5 % (on average by 2.6%) of article No. 4.

Summarizing the obtained results, it can be argued that after working for 125 days/1,000 hours, all these indicators in the nipple rubber changed. At the same time, its stiffness underwent the biggest changes – by 1.1 times.

When milking cows with nipple rubber No. 2–4, the milking machines did not fall off the cow's udder. When milking cows with nipple rubber No. 1 with the stiffness of 3,119.46±55.16 to 2,849.61±52.23 N/m, there were cases of milking machines falling off the cow's udder nipples.

The formulations of rubber used by manufacturers have some differences. Thus, a number of companies use rubber with the soot content of not more than 14 %, while in other companies, this value reaches 30 %. This, in turn, causes the differences in the operational and technological properties of nipple rubbers, in particular, of the stiffness and character of changes in the technical parameters of rubber during operation.

Analyzing the results of research into nipple rubber, it is possible to conclude that these articles are serviceable for 1,000 hours of operation. In this case, their readiness coefficient, determined from formula (2), is 1.

5. 2. The study of the inner surface of nipple rubber using electron microscopy

The state of the inner surface of nipple rubber is of great importance. In order to obtain photographs from the inner surface of nipple rubber DD 00.041A from the material of rubber mixtures produced by AO «Bratslav» (sample No. 3), we used an electronic raster microscope with a low-vacuum chamber and the system of energy disperse microanalysis REM-106.

Thus, according to electron microscopy, each point of the sample is sequentially irradiated by the focused electron beam, which moves around the studied surface like scanning of an electron beam in television systems. In the interaction of the probe electrons with the substance, there occur the corresponding signals of different physical nature (reflected and secondary electrons, Auger-electrons, X-rays, light, absorbed current, etc.), which are used for synchronous construction of an image on the monitor screen. Thus, the scheme of the study of the inner surface of nipple rubber can be presented as follows (Fig. 3).

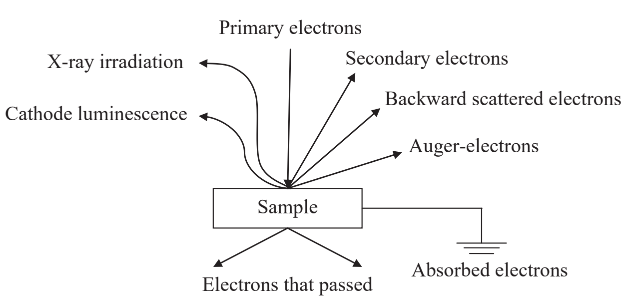
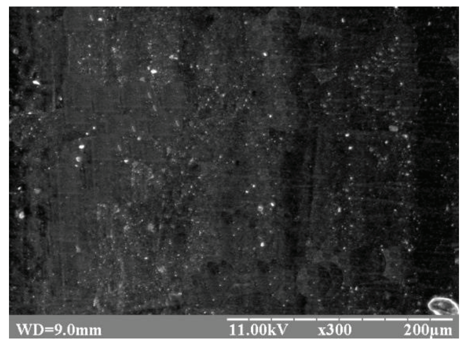


Fig. 3. Scheme of studying the inner surface of the nipple rubber by electron microscopy

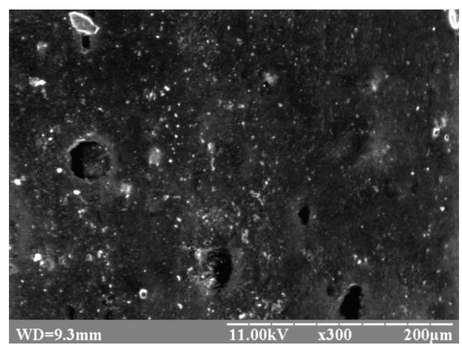
A change in the image scale was performed by the radiotechnical equipment rather than the electronic-optical system to form the image.

The results of electron microscopy are shown in Fig. 4.

a



b



c

Fig. 4. Inner surface of nipple rubber: *a* – of a new rubber article; *b* – after operation for 125 days/1,000 hours; *c* – after operation for 250 days/2,000 hours

It was established that the new article has a brilliant glossy inner surface, without any changes (Fig. 3, *a*).

As the term of operation increases, the rubber loses its primary properties, which leads to a decrease in its effectiveness. These processes occur gradually (Fig. 4).

Rubber wears out due to the dynamic nature of its operation. This element is subjected to the chemical influence of aggressive detergent solutions at elevated temperatures, which leads to the destruction of the inner surface. If we explore the rubber after the operation for 125 days/1,000 hours by the naked eye, it may look clean, but the study under a microscope gives a different picture. Fig. 3, *b* shows the inner surface of the rubber with magnification – one can be the small areas of growth of the bacterial colonies and surface hardening that lead to its abrasion. This is the reason for the damage of the animals' udder nipples during milking.

After working for 250 days/2,000 hours, microgaps and significant areas for the growth of bacterial colonies (Fig. 3, *c*) are formed on nipple rubber. Rubber loses its gloss and gets dark.

The studied parameters are important in determining the usability of nipple rubber and broaden the idea of the mechanism of its interaction with the environment.

5. 3. Studying the patterns of changes in the technical parameters of nipple rubber and establishing the nature of their influence

It was established that during the process of milking, the nipple rubber is saturated with fat, loses elasticity, stretched, its surface gets coarse and is coated with cracks. This leads to the loss of its properties and negative phenomena manifested in the reduction of its massage action, an increase in the duration of milking, accumulation of milk fat and unwanted microflora in rubber microcracks, the reduction of the milk quality. The basic technological parameters that are changed during the operation of nipple rubber are presented in Table 6.

Table 6

Changes taking place during the operation of nipple rubber

Specific features	Changes over time
Pulsation chamber is sealed from both ends of a milking cup	+
Massage of cows' udder nipple	+++
Strength of connection with the udder nipple	++
Fully-fledged and continuous milking of all parts of cows' udder	+++
Simplicity of cleaning	+++
Permissibility of contact with food products	–

Note. «–» – no changes; «+» – insignificant change; «++» – permissible change; «+++» – significant change

Thus, it was determined that the following parameters change substantially: massage of cows' udder nipples, milk yield, and cleansing ability. The tightness of the coupling of rubber with a milking cup does not change much during the operation. Along with it, the strength of coupling with the cow' udder nipple changes substantially. The admissibility of the contact with food products during the entire period of use of a rubber article is in an unchanged state.

Changes in the technical parameters of nipple rubber, depending on the service life are shown in Fig. 5.

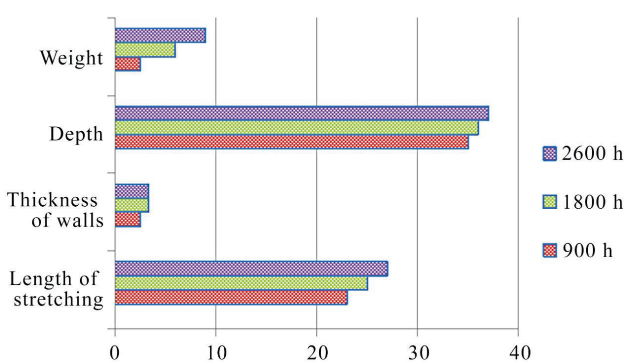


Fig. 5. Changes in the basic technical parameters of nipple rubber

It was found that all basic parameters of rubber are subject to changes during the operation (Fig. 6). Thus, the weight of the article changes by 8.5 %, the depth – by 37 %, wall thickness – by 2.5 %, and stretching length – by 27 %.

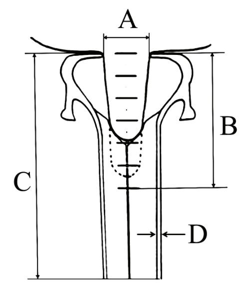


Fig. 6. Technical parameters of nipple rubber that change: *A* – inlet diameter; *B* – depth; *C* – stretching length; *D* – thickness

The reasons for the change of the technical parameters of nipple rubber are chemical and thermal loads. The effect of milk, water and detergents leads to saturation and swelling as well as washing out of the material of nipple rubber. The higher the operating temperature, the operating pressure/vacuum, the flow rate, the duration and frequency, the term of using the rubber, the more intensively these processes flow.

During the operation, the rubber changes its initial elasticity and shape. Consequently, during milking, the nipple rubber is raised and the udder nipple is pulled in.

When analyzing the results of the conducted research, both high positive and negative correlation dependencies between the technical parameters of nipple rubber were found (Table 7).

Table 7

Correlation dependence (r) of technological indicators of nipple rubber

Indicator	Correlation coefficient
Rubber stretching/service life	–0.986
Length of nipple rubber/service life	+0.919
Rubber stretching/rubber length	–0.864

Thus, it was determined that the length of the nipple rubber of milking cups is significantly affected by its service life: $r=+0.919$. The inverse relation was found in the comparison of rubber stretching to the service life and its length: $R=-0.986$ and $r=-0.864$.

The tendency to reduction of stiffness of the nipple rubber depending on its operation period was established (Table 8).

It was found out that there is a close relationship between the stiffness of the nipple rubber and the intensity of milk yield.

During the operation of the nipple rubber, it is stretched, which leads to a decrease in the stiffness of an article. Thus, if the stiffness in new nipple rubber was 3,120.46±40.26 N/m, after 6 months of its use, the above indicator decreased up to 2,567.23±37.65 N/m or by 1.2 times, which negatively affected the intensity of milk yield. Thus, when milking cows using new nipple rubber, the average milk yield intensity for a group of cows was 1.98±0.05 kg/min, and after 6 months this indicator decreased by 1.1 times – up to 1.76±0.03 kg/min.

Along with this, a high positive correlation dependence ($r=+0.939$) between the stiffness of nipple rubber and intensity of milk yield was established.

Table 8

Dependence of intensity of milk yield on the stiffness of nipple rubber, ($X \pm S_{\bar{X}}$)

Indicator	Service life						
	new	1 month	2 months	3 months	4 months	5 months	6 months
Stiffness of nipple rubber, N/m	3,120.46±40.26	2,970.28±35.45	2,822.39±38.32	2,707.25±29.87	2,642.13±32.94	2,597.41±39.04	2,567.23±37.65
Milk yield intensity, kg/min	1.98±0.05	1.97±0.04	1.92±0.04	1.89±0.04	1.84±0.05	1.81±0.04	1.76±0.03
Lim	1.41–2.16	1.40–2.00	1.42–2.00	1.36–1.93	1.32–1.84	1.30–1.73	1.27–1.63

Note: $P<0.01$

6. Discussion of the results of studying the changes in the technical parameters of nipple rubber for milking machines that occur during operation

The analysis of numerous experiments [23–25] indicates that the design of the rubber affects the characteristics of milking more than any other factor. Thus, at the initial stage of research, we set the purpose to establish the serviceability of nipple rubber of various manufacturers after operating for 125 days/1,000 hours. It was proved that the geometrical parameters, such as the length of the operating part, the diameter of the suction opening, the inner diameter of the tail part, undergo changes in the nipple rubber after the corresponding operating time. Stiffness and ovality of nipple rubbers change (Tables 2–5). The obtained results reveal the mechanism of a change in the operational characteristics of nipple rubber made of food silicone and rubber mixtures. This solves the problem of establishing the serviceability of these elements of milking machines.

In papers [26, 27], it was noted that the efficiency of cow milking is significantly influenced by the relevance of the diameter of the inlet outing of the nipple rubber head, and the wall thickness of an article determines its physical properties – the degree of softness/stiffness. The advantages of the conducted research over the specified ones include the establishment of changes in the complex of technical indicators, which fully reveals the picture of operational changes.

In paper [28], it is noted that it is necessary to monitor constantly the degree of stiffness of nipple rubber. During milking, too stiff rubber does not massage the entire area of the udder nipple tip and presses the skin. When using such rubber, the compression tact is reduced, which leads to the irritation of udder and cows falling ill with mastitis disease. The conducted studies supplement the earlier obtained results.

The inner surface of nipple rubber was studied at the next stage with the use of electron microscopy. Fig. 3 shows the scheme of research. Using a raster electron microscope, the images were obtained (Fig. 4). The obtained results of electron microscopy extend the understanding of the processes that flow during the operation of nipple rubber and make it possible to detect their influence on the inner surface of an article. Thus, the high resolution of an electron microscope made it possible to observe objects and changes that lay beyond the resolution of other laboratory equipment.

In paper [29], it is emphasized that the application of rubber with even slight changes in shape can lead to a significant deterioration in the state of the breast. Microscopic cracks on the inner surface of rubber are the cause for different deposits, which are an ideal nutrient for bacteria. Conducted research proves this theory, make it possible to approach critically the issue of application of nipple rubber beyond the terms of its use.

Subsequently, the regularities of changes in the technical parameters of nipple rubber were revealed and the nature of their influence was established. Thus, the determined technological parameters that are changed during the operation of nipple rubber were determined (Table 6). Advantages of the conducted research are the use of the points («–» – no changes; «+» – insignificant change; «++» – admissible change; «+++» is a substantial change) to determine the significance of the factors in the overall technological process. In addition, for clarity, the changes in the basic technical parameters of nipple rubber are presented in the form of a diagram (Fig. 5) and a scheme (Fig. 6). In the course of the research, we found the correlation dependences between the technical parameters of nipple rubber (Table 7), which makes it possible to interpret results in terms of the dependence of factors on each other.

During the studies, it was found out that there is a close relationship between the stiffness of the nipple rubber and the intensity of milk yield (Table 8). The conducted studies (within 6 months) prove the fact that rubber stiffness changes every month, and these changes adversely affect the milk yield intensity. This makes it possible to argue that in order to ensure the physiological functioning of the animal's breast, it is necessary to monitor constantly the state of nipple rubber.

The conducted studies are advantageously distinguished among the others [3, 7, 30] by their complexity, the use of innovative approaches (electron microscopy), and scalability. Along with this, due to the considerable variability of the structural values of nipple rubber, there occur some difficulties in completely solving the problem if a rubber article meets the physiological needs of an animal. This remains a problematic part of the total technological process of milking. In addition, the experiments that are performed under industrial conditions have a significant drawback, because they are carried out directly on animals. This causes special difficulties, because it is difficult to choose the cows that are similar in their physiology, and this significantly affects the results of the experiment, distorts actual information about the operation of the elements of a milking machine. In addition, one of the main disadvantages of modern testing is that the procedure of complex tests of milking machines was not developed, there is no relationship between laboratory and production research.

At present, there is a huge selection of nipple rubber for milking machines. The main thing is to take into consideration all its parameters and dimensions when buying, not to forget about the quality of the materials used in manufacturing and to take proper care of it. The conducted studies offer a real opportunity of taking into consideration the qualitative parameters of nipple rubber during selecting it.

With a large assortment of nipple rubber, there occurs a need to carry out further research in the field of the selection of nipple rubber for a milking herd, chosen according to the productivity of animals. That is why the research aimed at establishing the mechanism of the influence of nipple rubber, made of different material, on cows' udder nipple. This will make it possible to expand the area of both theoretical and practical knowledge in dairy cattle breeding, which would serve as a prerequisite to the improvement of milking equipment.

7. Conclusions

1. It was established that the serviceability of all nipple rubbers was 1,000 hours, which after working for eight hours per day corresponds to 125 days or 4 months of operation. After working for 1,000 hours, the stiffness of nipple rubber varies within significant limits and on average is: for articles made of silicone 2,849.61±52.23–3,343.76±51.26 N/m; articles made of the material of rubber mixtures – 2,597.76±78.26–2,821.43±55.24 N/m. The readiness coefficient of all articles is 1.

2. With the use of electron microscopy, it was found that there are changes in the internal surface of nipple rubber after operating for 125 days/1,000 hours and after the operation for 250 days/2,000 hours.

3. It was established that all the basic parameters of nipple rubber change during the operation: the weight of an article changes by 8.5 %, the depth – by 37 %, the wall thickness – by 2.5 %, and stretching length – by 27 %. The positive correlation between the stiffness of nipple rubber and the intensity of cows' milk yield (r=+0.939) was established.

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