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IDENTIFYING CHANGES IN THE MILKING RUBBER OF MILKING MACHINES DURING TESTING AND UNDER INDUSTRIAL CONDITIONS

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Milking rubber is the only part of the milking equipment that comes into direct contact with the cow's teats. The task is to establish the high-quality technical and technological characteristics of the rubber liners for milking machines. It has been established that milking rubber after 600–650 hours of operation acquires significant deflection in the range of 5.5±0.03–3.7±0.04 mm while a teat cup deformation varies within 1.3±0.02–3.5±0.05 mm. A positive correlation dependence of the milking rubber elasticity on the deformation of its teat cup (r=+0.948) has been found.

The method of passing the electric discharge was used to assess the readiness of milking rubber for use, whereby a variation coefficient of υ<10 % was determined for the milking rubber DD 00.041A AO «Bratslav», which makes it possible to estimate the product quality.

It was found that the change in the mass and volume of milking rubber over 72 hours of its treatment with the liquid SZHR-3 at t=150 °C exceeds the indicators obtained in contact with the liquid Skydrol LD-4 by more than 2.5 times. A positive correlation dependence of the milking rubber mass on its volume (r=+0.965) has been established.

It was found that at a rubber tension in the range of 0 to 90 N the duration of the deformation loss experienced by the milking rubber shell was not long; it is 0.05–0.06 s. With an increase in the service life of milking rubber to 4 months, there is a decrease in its tension, from 56–60 N to 43–45 N, which adversely affects the maximum speed of milk yield – it decreases by 1.5 times.

A positive correlation dependence of the milking rubber service life on the level of its bacterial insemination (r=+0.960) has been established

Keywords: milking rubber, rubber characteristics, rubber parameters, development, shell deformation

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1. Introduction

The milking machine is one of the main elements of the milking plant. Regardless of the structural features, it is designed to extract milk from the udder under the influence of a vacuum. Milking cups, equipped with milking rubber, are the controlling elements of the plant. The operational effectiveness of milking rubber affects not only the quality of cows' milking but also the state of their health. The cow produces milk not just as a result of the mechanical process by a milking machine suction but as a result of the manifestation of the physiological processes managed by the animal's brain. The functional activity of milking rubber largely influences the degree of these processes' effectiveness, the quantity of the hormone oxytocin to be released to the bloodstream, as well as the duration of its effect [1, 2].

Milking rubber is the most important element of the milking machine because it is in direct contact with the udder of an animal and has a direct impact on it. The choice of the milking rubber, the quality of the material, proper geometric parameters, as well as the physical and mechanical properties (rigidity, elasticity, integrity, etc.), affect the health of the udder teats, the speed of milk delivery, the quality of milk. Ultimately, the productivity and profitability of dairy production in general.

An analysis of numerous experiments [3–6] reveals that the design of milking rubber outperforms any other factor in affecting the characteristics of milking. Thus, to make the milking swift, with maximum completeness, and, at the same time, to prevent any harm to the udder teats, the milking rubber should be of high quality, that is, meet the technological parameters that take into consideration the physiologicality of animals as much as possible. And it should exert a positive impact on both the technological process of milking in general and the physiological state of cows in particular.

Therefore, our study is relevant in order to establish high-quality technical and technological characteristics for the milking rubber of milking machines. The task is solved by establishing changes in the properties of milking rubber in aggressive working fluids.

Such an approach would make it possible to expand the understanding of the qualitative characteristics of rubber products for milking. At the same time, this could reveal the mechanism of changes in the technical parameters of milking rubber and might lead to the rational use of rubber products for milking machines, hence its practical value.

2. Literature review and problem statement

Milking rubber is the only part that directly contacts the udder of an animal during milking. New milking rubber has a high elasticity, which ensures the effective massage of teats, udder stimulation, and maximum milk yield. When aging, it loses elasticity, stretches, its surface is rough and has cracks.

A change in the material's elasticity reduces the massaging effect when compressing milking rubber. The pressure of milking rubber on the udder teat is the main stimulation factor of milk yield, it is even more important than the frequency and duration of pulsations [7]. Non-elastic milking rubber has a much smaller massaging effect. In this regard, when using rubber of poor quality, with a large coefficient of stiffness, with cracks in the structure of the material, or the worn-out rubber that exhausted its service life set by the recommendations of the manufacturer, it is natural to expect a decrease in the stimulating effect of pulsation [8]. The reduced massage effect directly affects the circulation of the animal's blood and lymph. Milking cows when using poor milking rubber increases the risk of stagnation and swelling of teats thereby reducing the flow of milk. Along with this, the state of the udder teats could deteriorate rapidly. The specified factors such as stimulation deterioration, stagnation of blood, and subsequent swelling of teats, lead to an increase in the duration of the vacuum effect on udder teats. As a result, the protective mechanisms of teats become less effective. This is another factor that increases the danger of infection of teats when using poor-quality milking rubber, in addition to the increased bacterial insemination. It was established in [9] that using the milking rubber that had lost its primary technological indicators such as elasticity, elasticity, integrity, etc., increases the likelihood of slipping off of the suspension part of the machine. An incomplete milking increases the propensity of teats to accept new infectious agents.

To ensure the stability of milking conditions, it is pointed out in [10, 11] that milking rubber must retain its physical properties in a narrow range of values during the entire lifespan. Rubber should withstand multiple stretching in the milking cup without exposure to over-tension and not deform over time. In addition, milking rubber operates in an aggressive environment, constantly exposed to milk fat, hot water, and various detergents containing alkalis, acids, and chlorine [12]. By penetrating the rubber, fat molecules cause its swelling, thereby accelerating the processes of aging and destroying the polymer structure. Detergents remove most of the milk fat but they also affect the inner surface of the rubber, leading to its aging.

An analysis of numerous experiments [13–15] reveals that it is important to use affordable milking rubber of higher quality (taking into consideration the manufacturers offering products made from different materials) and ensure that milking should not employ old (used) products with a swollen and rough surface. It should be noted that the use of milking rubber with even small imperceptible changes in its shape and flexibility can lead to a significant deterioration of the animal's breast. Such rubber hardens quickly, swells, and cracks. In addition, the inner walls undergo the formation of small cracks that create ideal conditions for the development of bacteria and various deposits.

Comparative studies of different milking systems [16] indicate that milking rubber with such technological parameters that do not meet the physiological needs of animals can lead to the emergence of subclinical mastitis. Losses in milk when using such rubber could amount, according to various estimates, to up to 5 %. Therefore, the first requirement for the healthy milking of cows is to use the overall high-quality milking rubber.

To reach the maximal effect of the use of milking rubber, it is necessary to properly calculate the conditions of its application and choose it correctly for animals at a farm. The best results from using the properly selected rubber would be demonstrated at a farm or by a group of animals whose level of milk yield, the udder and teat sizes are maximally similar.

There are many proposals regarding milking rubber for various milking equipment in the market, including made abroad.

There are products manufactured by factories or workshops locally. Typically, these are models copied from the originals. These products are similar to originals in their physical appearance but there is no information on their performance [17].

Analogs of the original: such products are offered by companies that, as a rule, are not engaged in the supply of complete dairy equipment, its regular maintenance.

Therefore, a milk producer operating milking equipment should have information on milking rubber and be guided by the basic principles when choosing it.

An earlier study into the operational properties of milking rubber was carried out based on the pre-known time of its service life duration, which excluded the possibility of establishing the high-quality technical characteristics for new products [18].

The issues relating to the functioning of milking equipment are addressed in works [19–23]. However, there are unresolved issues regarding the quality technical characteristics of milking rubber made by various manufacturers. The reason for this is the cost associated with the timing of the relevant research and observations.

Therefore, it is advisable to conduct a study aimed at establishing the high-quality technical and technological characteristics of milking rubber for milking machines.

3. The aim and objectives of the study

The aim of this study is to identify changes in the milking rubber of milking machines in the process of testing it and under industrial conditions. This would make it possible to find an adequate solution when choosing rubber products for milking the herd.

To achieve the set aim, the following tasks have been solved:

– to detect technical indicators (deflection in the milking cup of the working surface and the deformation of the upper part, which is shaped like a teat cup, when using the designed devices) for the new milking rubber made by various manufacturers, as well as following its operation;

– to establish changes in the mass, volume, relative residual deformation, and aging coefficient depending on the stress of milking rubber exposed to aggressive working fluids;

– to establish the tension force effect on the milking rubber as a factor that largely determines the nature of compression in the sleeve of a milking cup on the duration of deformation loss by the shell of the milking rubber and on the indicators of milk yield;

– to determine the level of bacterial insemination of milking rubber over the duration of its operation and its effect on the quality of milk.

4. Materials and methods to study the qualitative technical characteristics of milking rubber for milking machines

4. 1. Methodology to study the qualitative indicators of new milking rubber made by different manufacturers, as well as following its operation

Our experiment was conducted at the State Enterprise «Experimental Farm «Gontarivka», Vovchansky region, Kharkiv oblast (Ukraine), with tethered dairy cows of the Ukrainian black-spotted dairy breed. The animals were milked to the milking line.

The study analyzed the following products:

– BouMatic rubber (analog DD.00.041A) made from the food silicone material made by BouMatic Robotics (Moncton, Canada);

– De Laval rubber (analog DD.00.041A) from the material of rubber compounds manufactured by Zhangjiagang Chuangpu Machinery Co., Ltd. (Jiangsu, China);

– DD 00.041A rubber from the material of rubber compounds manufactured by AO «Bratslav» (Bratslav, Nemyriv region, Vinnytsia oblast, Ukraine);

– DD 00.041A rubber from the material of rubber compounds manufactured by AT «Agrotechimport» (Volodymyr, Russia).

The choice of these products is justified by that they are widely represented in the market of milking equipment and are in demand [3].

We determined the condition of milking rubber after 600–650 hours of its operation, the period over which milking rubber actively loses its primary technical and technological properties. It is during this time interval that the rubber product is most actively used, after which it loses its primary technical parameters. Therefore, its subsequent application (longer than 650 hours) is impractical in terms of scientific aspect and based on data from service centers.

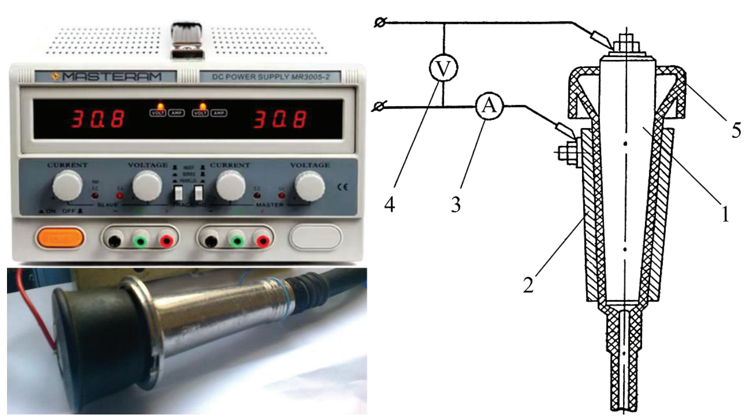
At the initial stage, geometric measurements established the complete compliance of all the products with specifications [24].

A procedure from [25] was used to select the samples – we performed the initial inspection of the products, established their suitability for tests, and discarded rubber with defects. The algorithm for testing milking rubber was followed, the techniques and manipulations required for testing were applied. Specifically, we measured the deformation of a milking rubber teat cup, its elasticity, and flexibility.

A device shown in Fig. 1 was used for determining the integrity of the milking rubber for milking machines.

The device consists of the internal and external electrodes, made, respectively, in the form of cone core 1 and cartridge 2, whose diameters are larger than the corresponding diameters of the milking rubber by 1.2–1.3 times, electric current meter (amperemeter) 3, and current-voltage meter (voltmeter) 4. The device is connected to an electrical current source. Voltmeter 4 is used to set the voltage (up to 30 V) required for finding defects, which is fed to cartridge 2 and cone core 1.

The characteristics of the power supply unit (Fig. 1, *a*) are as follows: adjusting the current and voltage values is carried out by potentiometers separately in each channel; the output current and voltage values in each channel are controlled on separate LED panels. The measurement error is not more than 1 %±2 units for voltage and 2 %±2 units for current.



a *b*

Fig. 1. Device for finding defects in the milking rubber of milking cups using an electric current: *a* – physical appearance of the device with the adjusTable power supply unit Masteram MR3005-2; *b* – the scheme of the device: 1 – conic core; 2 – cartridge; 3 – electric current meter; 4 – current voltage meter; 5 – the examined milking rubber [26]

The control we chose was the milking rubber DD 00.041A from AO «Bratslav», which passed the appropriate tests, and established itself as a reliable element of the milking equipment [3].

The principle of operation of the device is as follows: if milking rubber 5 has cracks, the electrical discharge freely passes through them leading to a breakdown.

In order to determine the quality of the milking rubber DD 00.041A from AO «Bratslav» in terms of the variance coefficient, we used our own three-stage gradation (Table 1) [27]. The interpretation of the materials from the cited source reveals that this very distribution is correct when using a variance coefficient.

Table 1

Grouping of milking rubber based on the variance coefficient

Group	Variance coefficient value
I	to 10 %
II	from 10 to 20 %
III	above 20 %

The classification of the quality of samples of milking rubber is as follows (according to Table 1):

– group I – the quality of rubber is considered to be excellent (the variance coefficient value (υ) is to 10 %);

– group II – the quality is good (the variance coefficient value (υ) is from 10 to 20 %).

This distribution is due to that the worn-out milking rubber has a maximum variance coefficient of 31.2 %. New milking rubber has a minimum variance coefficient of 3.9 %. The specified initial data were used to develop the appropriate classification.

4. 2. Procedure to study changes in the properties of milking rubber in aggressive working fluids

The experimental samples of milking rubber were treated with the liquid SZHR-3 at a temperature of 150 °C. In parallel, at a temperature of 150 °C, the rubber was aged in the liquid Skydrol LD-4. These liquids are new and effective in terms of their use in studying rubber products [17].

The basic physical-chemical indicators of the working fluid SZHR-3 are as follows: aniline point, 71–75 °C; the kinematic viscosity at 100 °C is 4.5–5.0.

The basic physical-chemical indicators of the working fluid Skydrol LD-4 are as follows: viscosity at 100 °C is 11.42; the freezing point is 62 °C.

A change in the mass after exposure to liquid aggressive environments was determined in line with [28]. The method implied that the nondeformed standard rubber samples in the form of plates were treated with liquid aggressive environments at the predefined temperature and aging time. Then we determined their stability based on the change in the value of one or more indicators such as the original mass of the sample.

The relative residual deformation due to the compression in the air was determined in line with [29]. The samples in the form of cylinders were exposed to the static compression deformation; the value of the relative residual deformation was used to determine the ability of rubber to retain elastic properties in a compressed state under the specified conditions.

The coefficient of aging due to the compression stress was determined using method B [30]. The method implies (points 2.1–2.4.4 in [30]) measuring a compression force at a temperature of 23±2 °C of the samples, compressed to the predefined deformation, before and after their aging over the pre-set time at an elevated temperature, and calculating the stress (Fig. 2).

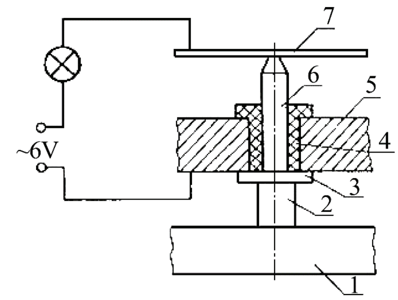


Fig. 2. Electro-mechanical diagram for determining an aging coefficient based on compression stress: 1 – lower plate; 2 – a sample of milking rubber; 3 – flange; 4 – guide bushing; 5 – upper plate; 6 – rod; 7 – spring

The measuring device used to determine the coefficient of aging based on compression stress consists of variable flat calibrated springs of different stiffness and an indicator with a scale division of 0.01 mm. The rods, placed in the holes of the removable slab of the clamp, slide in the guide bushings made of the electrical insulation material. The rods should fall under the influence of natural mass, which should not exceed 50 m [30].

The top end of the rod is a spot contact with the spring of the measuring device (Fig. 2).

The lower end of the rod ends with a flange designed for electrical contact with the upper slab of the clamp.

The moment of the start and end of the measurement was registered by a signal from the light bulb. The voltage of the electric-signal system was within 6 V.

Samples in the form of cylinders were placed in clamps and aged in the working environments at the pre-set temperature and duration. The force of compression before and after the influence of the environment was determined; the ratio of these values was used to estimate the coefficient of aging.

One clamp hosted the samples that differed in height by not more than ±0.05 mm. The compression rate of 20, 30, and 40 % was allowed.

We kept the clamps with the compressed samples at a temperature of 23±2 °C over 30 minutes. At the same temperature, the compression force in the samples was measured. To this end, we placed the clamp in the assembled form with the samples installed in it on the movable plate of a relaxometer so that the axis of the rod of the first sample coincided with the axis of the power meter rod. In this case, a further slight clamping of a sample was allowed.

A variable calibrated spring was installed, selecting it for a given tested series of the samples so that the maximum deflection of the spring did not exceed 1 mm.

The indicator was to zero position. The movable plate of the device was lifted with a lifting screw and brought the cone of the clamp's rid to the contact with the calibrated spring (the signal lamp was lit).

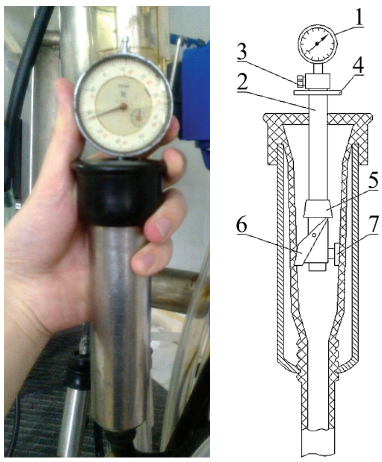
The movable plate was continued to lift until the electrical circuit was unlocked (the signal light goes off). Indicator readings were acquired at the time of opening the circuit.

The measurements were repeated three times; we calculated the mean arithmetic of the three indicator readings.

Permissible discrepancies did not exceed ±0.02 mm from the derived average value for each sample.

4. 3. Procedure to study the impact of milking rubber tension on the loss of deformation by the shell and the indicators of milk yield

We determined the tension of milking rubber in the sleeve of the milking cup using the device shown in Fig. 3.



a *b*

Fig. 3. Device for determining the tension of milking rubber in milking cups: *a* — physical appearance; *b* — device diagram: 1 — counting unit; 2 — body; 3 — fixing screw; 4 — stop; 5 — movable bushing; 6 — rotary lever; 7 — stationary insert

The device consists of counting device (a clock-type indicator) 1 with a measurement limit of up to 25 mm, body 2, fixing screw 3, stop 4, movable bushing 5, rotary lever 6, and stationary insert 7.

The principle of operation of the device is as follows: the ready-to-use device (the clock-type indicator readings are in the original position) is entered into the middle of the milking rubber. There, it is placed in an upright position while stop 4 limits the depth of its introduction. Rotary lever 6 and stationary insert 7 are in contact with the inner surface of the rubber, thus determining its tension. The value of the rubber tension is determined from the clock-type indicator's scale of type 1 [31].

The average intensity of milk yield (Q) in kg/min was calculated as follows (1):

$$Q=\frac{\sum(q_1+q_2)}{\sum(t_1+t_2)}, \qquad (1)$$

where q_1 is the amount of machine milking, kg, q_2 is the value of machine post-milking, kg, t_1 is the duration of machine milking, min, t_2 is the duration of machine post-milking, min.

The maximum intensity of milk yield was determined using the chart, over 15 s of milking when the maximum milking speed was observed [32].

4. 4. Procedure to study the level of bacterial insemination of milking rubber over the time of its operation and its impact on the quality of milk

Washings were collected in order to determine the degree of insemination of the inner surface of milking rubber using sterile cotton swabs mounted on wooden sticks, 2–3 mm thick. The cotton swabs were placed in sterile tubes with 5 cm^3 of a sterile physiological solution of sodium chloride so that the swab was 2–3 cm above the level of liquid in the tube. Before washing collection, the swab was moisturized in a physiological solution; the excess liquid was removed by pressing the swab against the inner surface of the upper half of the tube. We collected washing off the surface with a sterile stencil, after which the swab was again placed in a test tube and immersed in the liquid. The seeding to determine bacterial insemination was performed no later than 3 hours after the collection of the material from its consecutive 10-fold dilution from 10^{-2} to 10^{-6} in a physiological solution.

The total bacterial insemination of milk was examined in line with [33], based on the property of mesophilic aerobic and optional anaerobic microorganisms to breed on dense nutrient agar at a temperature of 30±1 °C for 72 hours.

The number of grown colonies was counted in each Petri cup. The total number of bacteria per 1 cm^3 or 1 g of milk was calculated as follows (2):

$$\tilde{O}=n\times 10^{m}, \qquad (2)$$

where n is the number of colonies counted in a Petri cup, m is the number of ten-time dilution.

The total number of enterobacteria was determined by seeding the diluted milk and washings on the Endo environment in the amount of 0.1 cm^3, followed by stirring with a spatula. The seeds were incubated for 18–20 hours at a temperature of 36.5±0.5 °C, and then we registered the number of colony-forming units.

5. Results of studying the qualitative technical characteristics of milking rubber for milking machines

5. 1. Studying the technical indicators of new milking rubber made by different manufacturers, as well as following its operation

During the research, we have established (Table 2) that the rubber Bou Matic (Canada) is characterized by the best elasticity and greatest flexibility – on average 5.3 mm vs. 4.8 mm compared to De Laval rubber (China), 3.8 mm for the rubber by AO «Bratslav» (Ukraine), and 3.8 for the rubber DD 00.041A by AT «Agrotechimport» (Russia).

The deflection range for the Bou Matic rubber was from 5.2±0.02 mm to 5.4±0.04 mm; the rubber De Laval – from 4.7±0.03 mm to 4.9±0.05 mm. For the rubber DD 00.041A by AO «Bratslav», this indicator was in the range of 3.7±0.04 mm to 4.0±0.06 mm; the rubber DD 00.041A by AT «Agrotechimport» – in the range from 3.7±0.04 mm to 3.9±0.06 mm.

In the rubber Bou Matic, the deformation of the teat cup was the smallest – 1.3±0.02–1.6±0.03 mm. The largest deformation of the teat cup was observed in the rubber DD 00.041A by AT «Agrotechimport» – 3.3±0.03–3.5±0.05 mm.

Comparing the results obtained for all rubber samples, a significant range of their deflection (from 5.5±0.03 to 3.7±0.04 mm) and deformation of the teat cup (from 1.3±0.02 to 3.5±0.05 mm) was established. This indicates that rubber products have different technical characteristics, and, as a result, differently affect the udder teats during milking. And it is the rigidity of the product that is a decisive factor in the impact on the body of the cow – its teats during milking. This factor confirms the prospects of further research aimed at detecting the impact of rubber products on the teats of cows in terms of their various design and structure.

Table 2

Quality of milking rubber, ($X\pm S_{\bar{X}}$)

Rubber manufacturer and No.	Rubber deflection, mm	Teat cup deformation, mm
Bou Matic No. 473219	5.2±0.03	1.3±0.02
Bou Matic No. 498710	5.3±0.02	1.5±0.03
Bou Matic No. 435373	5.4±0.04	1.5±0.04
Bou Matic No. 477361	5.5±0.02	1.6±0.03
Bou Matic No. 467591	5.3±0.03	1.4±0.03
Bou Matic No. 496743	5.5±0.03	1.5±0.04
Bou Matic No. 420569	5.2±0.02	1.4±0.03
Bou Matic No. 457339	5.2±0.04	1.3±0.02
De Laval No. 786002	4.8±0.03	1.9±0.02
De Laval No. 714731	4.9±0.04	2.0±0.02
De Laval No. 716087	4.7±0.03	2.0±0.03
De Laval No. 774651	4.8±0.04	2.1±0.03
De Laval No. 799079	4.8±0.03	1.9±0.02
De Laval No. 735490	4.7±0.04	1.9±0.03
De Laval No. 808082	4.9±0.05	2.1±0.02
De Laval No. 818081	4.8±0.04	2.0±0.02
DD 00.041A No. 451*	4.0±0.06	3.1±0.03
DD 00.041A No. 451*	3.8±0.04	3.2±0.04
DD 00.041A No. 451*	3.9±0.04	3.1±0.04
DD 00.041A No. 451*	3.9±0.05	2.9±0.04
DD 00.041A No. 451*	3.8±0.04	3.1±0.03
DD 00.041A No. 451*	3.9±0.04	3.2±0.02
DD 00.041A No. 451*	3.7±0.04	3.1±0.03
DD 00.041A No. 451*	3.9±0.04	3.1±0.04
DD 00.041A N/A**	3.7±0.05	3.5±0.05
DD 00.041A N/A**	3.8±0.04	3.5±0.04
DD 00.041A N/A**	3.9±0.06	3.4±0.03
DD 00.041A N/A**	3.8±0.05	3.3±0.03
DD 00.041A N/A**	3.8±0.04	3.5±0.04
DD 00.041A N/A**	3.7±0.05	3.4±0.05
DD 00.041A N/A**	3.7±0.04	3.3±0.04
DD 00.041A N/A**	3.8±0.05	3.4±0.06

*Note: $P<0.05$; * – milking rubber by AO «Bratslav»; ** – milking rubber by AT «Agrotechimport»*

Along with this, a high positive correlation dependence ($r=+0.948$) of the elasticity of milking rubber on the deformation of its teat cup has been established.

Thus, it can be argued that all types of rubber after 600–650 hours of operation were in a satisfactory condition (the deformation of the teat cup did not exceed 5 mm, the deflection of the rubber did not go beyond 7 mm).

In order to identify qualitative indicators of new milking rubber made by different manufacturers, as well as after 5 months of its use, we performed the relevant study (Table 3).

Table 3

Determining the integrity of milking rubber for milking machines

Milking rubber	Quantity, pcs.	Rubber products with defects, pcs.	
		application start	in 5 months of operation
Bou Matic	200	1	–
De Laval	200	1	1
DD 00.041A*	200	–	1
DD 00.041A**	200	10	3

*Note: * – milking rubber by AO «Bratslav»; ** – milking rubber by AT «Agrotechimport»*

It was established that the best reliability is demonstrated by the milking rubber DD 00.041 manufactured by AO «Bratslav» and the rubber Bou Matic. The worst indicator is demonstrated by the rubber DD 00.041A by AT «Agrotechimport» – in a batch of 200 pcs, 10 products (5 %) were found, through which electrical discharge freely passes.

The results of our research confirm the fact that not all teat rubber has optimal technical parameters. Its leakage (cracks, breakdowns, etc.) could lead to dropping a milking cup during milking as a result of the «depressurization» of the system.

Our further study (in accordance with [25]) of the milking rubber DD 00.041A by AO «Bratslav» found that its average arithmetic elongation value (X_i) is 170.9, and $\sum(X_i-X)^2$ is 2,565.

It has been established that the rms deviation of the rubber elongation value (σ) is 16. Accordingly, the variance coefficient (υ) is 9.36 %.

Thus, it has been determined that the milking rubber made by AP «Bratslav» belongs to group I – the quality is considered to be excellent (the value of the variance coefficient (υ) is to 10 %).

The reported comprehensive studies expand the idea of mechanisms inherent in milking rubber during operation. An assessment has been given regarding the readiness of milking rubber for use, thereby establishing for the rubber DD 00.041A by AO «Bratslav» a variance coefficient, which makes it possible to estimate the quality of the product.

5. 2. Studying changes in the properties of milking rubber in aggressive working fluids

When analyzing the results obtained (Table 4, Fig. 4, 5), it was found that the change in the mass and volume of rubber from all manufacturers over 72 hours of exposure to the liquid SZHR-3 exceeds, by more than 2.5 times, the indicators obtained in contact with the liquid Skydrol LD-4.

As for the coefficient of aging due to tension, in the environment of SZHR-3, it ranged from 0.72 (for the rubber DD 00.041A*) to 0.82 (for the Bou Matic rubber). In the Skydrol LD-4 environment, this indicator demonstrated the highest value for the Bou Matic rubber (0.42), and the lowest – for the rubber DD 00.041A* (0.23). Our results of the quality of milking rubber in terms of aging due to tension indicate that rubber products have a wide range of this indicator. In this case, the coefficient of aging due to tension in the environment of SZHR-3, compared to the Skydrol LD-4 environment, was less by >2 times.

Table 4

Change in the properties of milking rubber after aging in the liquid environment at t=150 °C for 72 hours

Rubber	Indicator	Indicator value after aging in liquids	
		SZHR-3	Skydrol LD-4
Bou Matic	Mass change, %	50.10	15.25
	Volume change, %	62.54	16.84
	Relative residual deformation, %	–55	36
	Coefficient of aging due to tension	0.82	0.42
De Laval	Mass change, %	58.09	16.35
	Volume change, %	65.38	18.25
	Relative residual deformation, %	–54	40
	Coefficient of aging due to tension	0.79	0.38
DD 00.041A*	Mass change, %	58	19.55
	Volume change, %	95.34	23
	Relative residual deformation, %	–75	48
	Coefficient of aging due to tension	0.72	0.23
DD 00.041A**	Mass change, %	63	22.47
	Volume change, %	98.25	26
	Relative residual deformation, %	–79	54
	Coefficient of aging due to tension	0.73	0.28

*Note: P<0.05; * – milking rubber by AO «Bratslav»; ** – milking rubber by AT «Agrotechimport»*

ronment of SZHR-3 (min=50.10 %, max=63 % – variational values for mass change; min=62.54 %, max==98.25 % – regarding volume change) and Skydrol LD-4 environment (min=15.25 %, max=22.47 % – variational values for mass change; min==16.84 %, max=26 % – regarding volume change) are explained by different physicochemical indicators of the working fluids. In this case, our results coincide with all the values in the dependences, which confirms their reliability.

During the research, a high positive correlation dependence (r=+0.965) of the milking rubber mass on its volume has been established. The calculation of the Student's t-criterion when comparing the specified average values (the number of the degrees of freedom f=6, critical value t=2.447, at a significance level of α=0.05) makes it possible to assert the adequacy of the data obtained.

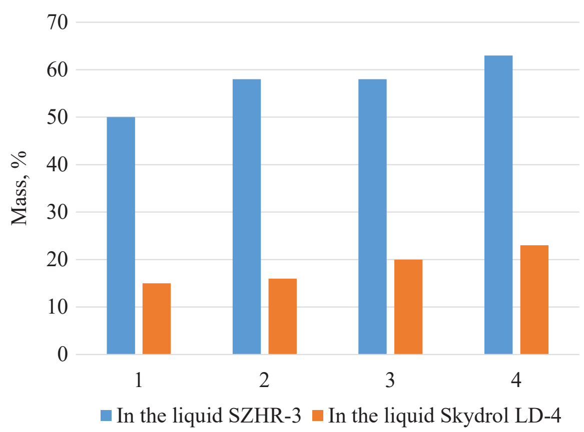


Fig. 4. Change in the mass of milking rubber in the environment of liquids at t=150 °C for 72 hours: 1 – rubber Bou Matic (analog to DD.00.041A) from the material of food silicone; 2 – rubber De Laval (analog to DD.00.041A) from the material of rubber compounds; 3 – rubber DD 00.041A from the material of rubber compounds manufactured by AO «Bratslav»; 4 – rubber DD 00.041A from the material of rubber compounds manufactured by AT «Agrotechimport»

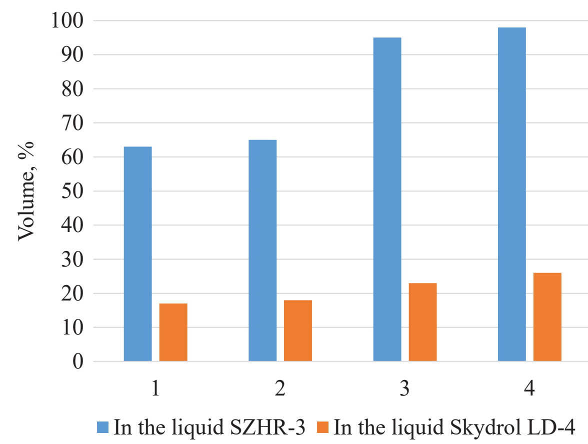


Fig. 5. Change in the volume of milking rubber in the environment of liquids at t=150 °C for 72 hours: 1 – rubber Bou Matic (analog to DD.00.041A) from the material of food silicone; 2 – rubber De Laval (analog to DD.00.041A) from the material of rubber compounds; 3 – rubber DD 00.041A from the material of rubber compounds manufactured by AO «Bratslav»; 4 – rubber DD 00.041A from the material of rubber compounds manufactured by AT «Agrotechimport»

The relative residual deformation due to the swelling of milking rubber improves – the maximum value (54 %) in the Skydrol LD-4 environment was demonstrated by the rubber DD 00.041A** and the minimum value (36 %) – by the Bou Matic rubber.

In the environment of the liquid SZHR-3, this parameter produced negative indicators. Thus, the smallest relative residual deformation (79 %) was registered for the rubber DD 00.041A**, and the largest (54 %) – for the rubber De Laval.

Significant discrepancies in the results of changes in the mass and volume of milking rubber (Fig. 4, 5) in the envi-

5. 3. Studying the impact of milking rubber tension on the loss of deformation by the shell and the indicators of milk yield

The tension value for the milking rubber in the sleeve of the milking cup in the range from 0 to 90 N leads to a change in the duration of the deformation loss by the milking rubber shell in a narrow time range of 0.05–0.06 s (Fig. 6).

The relationship between the duration of the deformation loss by the milking rubber shell on the value of its tension is determined by the polynomial dependence $y=-0.0003x^2+0.0035x+0.0505$ (R^2=0.9333) with a high regression coefficient (R^2=0.9333). The linear dependence of these factors has a low regression coefficient $R^2=0.6$. Thus, the tension parameters of milking rubber in the specified ranges do not affect the duration of the deformation of the shell of milking rubber in the dynamic mode of its operation.

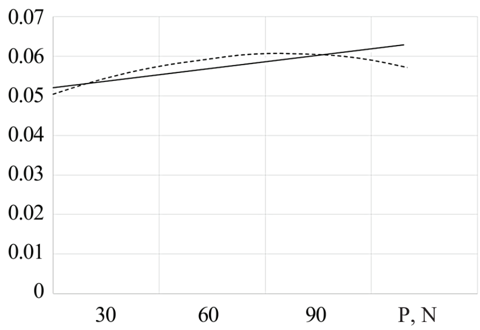


Fig. 6. Dependence of the duration of the deformation loss by the milking rubber shell on the value of its tension in the sleeve of the milking cup: —— – linear dependence $y=0.001x+0.053$ ($R^2=0.6$); ----- – polynomial dependence $y=-0.0003x^2+0.0035x+0.0505$ ($R^2=0.9333$)

Restoration of the elastic properties of milking rubber is a change in the amount of deformation over time after removing the load from the sample. Since the internal forces in the rubber, freed from the load, come into balance slowly, the elastic consequences under static conditions are manifested over a long time.

Next, in order to establish the dependence of milk yield indicators on the tension of the milking rubber DD 00.041 manufactured by AO «Bratslav», we carried out the corresponding study (Table 5).

Table 5

Indicators of milk yield depending on the tension of milking rubber, $X\pm S_{\bar{X}}$), $n=5$

Indicator	Milking rubber service life, months				
	0	1	2	3	4
Tension, N	56–60	52–54	51–53	46–48	43–45
Maximal milk yield speed, l/min	2.0±0.25	1.8±0.54*	1.6±0.43*	1.4±0.29*	1.3±0.57*
Average milk yield speed, l/min	1.7±0.55	1.6±0.45*	1.4±0.47*	1.2±0.50*	0.9±0.64*

*Note: * – the level of confidence probability for the average values p<0.5.*

Table 4 shows that with an increase in the service life of milking rubber up to 4 months there is a decrease in its tension, from 56–60 N to 43–45 N. The maximum speed of milk yield decreases from 2.0±0.25 l/min to 1.3±0.57 l/min, or by 1.5 times ($p<0.5$), and the average milk yield speed – from 1.7±0.55 l/min to 0.9±0.64 l/min, or by 1.9 times ($p<0.5$).

When analyzing the results of our studies, a high positive correlation dependence of the milking rubber tension, which changes during the lifetime, on the maximum speed of milk yield ($r=+0.980$) was established. A correlation dependence of $r=+0.966$ was established of the milking rubber tension on the average speed of milk yield. The calculation of the Student's t-criterion when comparing the specified average values (the number of the degrees of freedom, $f=198$; critical value, $t=1.973$; the level of significance, $\alpha=0.05$) makes it possible to assert the adequacy of the data obtained.

5. 4. Studying the level of the bacterial insemination of milking rubber over the time of its operation and its effect on the quality of milk

Milking rubber in the process of machine milking is in contact not only with the cow's udder but also directly with milk. Therefore, the sanitary condition of this working unit affects the initial degree of milk insemination by microorganisms.

Our study has found that after one month of operation the sanitary condition of the milking rubber DD 00.041 manufactured by AO «Bratslav» was in satisfactory condition – 7.5±3.26 thousand CFU of microorganisms resided on 1 cm^2 of its inner surface (Table 6).

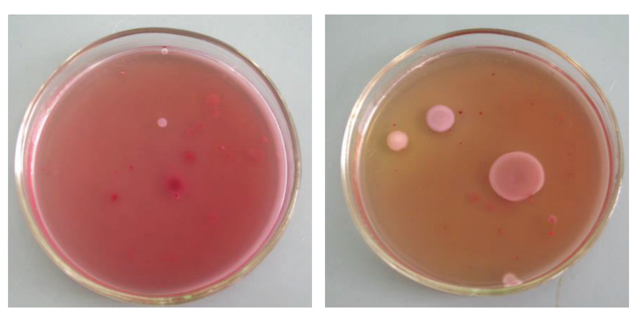
Table 6

Bacterial insemination of milking rubber and milk, $(X\pm S_{\bar{X}})$, $n=5$

Operation time, month	Bacterial insemination of milking rubber, CFU thousand/cm^2	Bacterial insemination of milk, CFU thousand/cm^3
1	7.5±3.26	122.4±21.52
2	13.4±4.33	215.6±25.33
3	20.5±4.56	318.5±19.61
4	36.7±3.58	412.4±26.24
5	62.3±4.29	551.3±25.16
6	89.4±5.11	711.6±24.85

With the increase in the duration of using milking rubber, the level of its bacterial insemination significantly increased. Thus, after 3 months of operation, the number of microorganisms per 1 cm^2 of the inner surface increased by 2.7 times and amounted to 20.5±4.56 CFU thousand/cm^2 (Fig. 7, *a*).

After 6 months of using milking rubber, 1 cm^2 of its inner surface hosted the increased number of microorganisms, by 11.9 times, it amounted to 89.4±5.11 thousand CFU at $p<0.001$ (Fig. 7, *b*).



a *b*

Fig. 7. Bacterial insemination of milking rubber: *a* – after 3 months of operation; *b* – after 6 months of operation

Such milking rubber is an additional source of milk insemination. It was found that 1 cm^3 of milk contains 711±24.85 thousand CFU, which is 5.8 times larger than the indicator obtained during the operation of milking rubber during the first month, which also has a high degree of probability (p<0.001).

The analysis of our study results has established a high positive correlation dependence of the levels of bacterial insemination of milking rubber on milk received (r=+0.984). At the same time, a slight decrease in the correlation coefficient between the service life of the milking rubber and the level of its bacterial insemination (r=+0.960) has been established.

6. Discussion of results of studying the qualitative technical characteristics of milking rubber for milking machines

Milking rubber is an intermediate link between the animal and the milking machine, so it is subject to strict requirements. For it to withstand the high levels of mechanical load and chemical impact, a range of operational tests and quality checks are carried out. These trials begin in the initial development phases and continue at a dairy farm [34, 35]. Thus, at the initial stage of our research, the goal was to identify qualitative indicators of new milking rubber made by different manufacturers, as well as after operation.

It has been proven that milking rubber after due operation undergoes changes in elasticity leading to the deformation of the teat cup (Table 2). Along with this, the integrity of the milking machines' rubber (Table 3) was determined. In addition, at this stage, we determined, based on the variance coefficient (υ), the quality of the milking rubber made by AO «Bratslav».

The results obtained reveal the estimating technical indicators of new milking rubber and the mechanism of changes in the operational characteristics of rubber products. This solves the task of choosing a more rational product, followed by forecasting the durability of its operation.

Works [36, 37] state that milking rubber is the only component of the milking machine that comes into close contact with the animal's udder. Its design parameters affect the effectiveness of the milking process. The merits of our study, compared to the cited works, include the identification of the qualitative indicators of new milking rubber made by various manufacturers, as well as after operation, which fully reveal patterns in the operational characteristics of rubber products.

The needs of modern agricultural production for high-quality milking and dairy equipment, the compositional nature of their components, and the complex dependence of the technical and technological properties, define one of the tasks for the modern technology of milking rubber – the development of rubber with the predefined technical and technological indicators. The difficulty of this issue is that it is necessary to choose, among many ingredients, 10–15 components whose mixture could produce a rubber compound with the required technical parameters.

Paper [38] emphasizes that the rubber mixture formulation may include more than 20 components in a balanced proportion. Soft and elastic rubber is designed to provide a caring and effective massage of teats. Components that are part of milking rubber should warrant the necessary mechanical stability and strength, resistance to prolonged exposure to temperature changes, UV rays, milk fat, chemical detergents, and mechanical influences. Therefore, at the next stage of our research, the goal was to establish changes in the properties of milking rubber in aggressive working fluids – SZHR-3 and Skydrol LD-4 (Table 4). We investigated changes in the mass and volume of milking rubber in the liquid environment at t=150 °C for 72 hours (Fig. 4, 5); the relative residual deformation and a coefficient of aging due to tension were established. During the research, a high positive correlation dependence (r=+0.965) of the milking rubber mass on its volume was established.

It should be noted that testing milking rubber for hardness produces rough measurements and can be carried out only at very limited deformations, which may not correspond to the operation of the product. In addition, the data obtained from these tests may yield a large range of values. The poor reproducibility of results is due to the uneven thickness of the sample, differences in its geometry. Therefore, we applied a procedure, which implied the use of aggressive working fluids. This approach is innovative in the study of milking rubber.

To obtain rubber by vulcanization, it is necessary to have from 20 to 60 percent of the base – caoutchouc. The rest of the composition may vary depending on the required properties, operating conditions, production technology, as well as the requirements for the product. Rubber elasticity is 4–5 times less than that in steel but this characteristic is nonlinear and is relaxing in nature: it depends entirely on the magnitude, speed, time, temperature, frequency, as well as the load mode. Reverse deformation can equal from 500 to 1,000 %. Therefore, the next purpose of our study was to determine the impact of the milking rubber tension in the sleeve of a milking cup on the duration of the deformation loss by the milking rubber shell and the indicators of milk yield. We thus established the dependence of the duration of the deformation loss by the shell of milking rubber on the magnitude of its tension in the sleeve of a milking cup (Fig. 6). It was found that with an increase in the service life of milking rubber up to 4 months there is a decrease in its tension from 56–60 N to 43–45 N. This affects the maximum speed of milk yield – it decreases by 1.5 times (Table 5).

The results obtained reveal the mechanism of influence of the milking rubber tension on the indicators of milk yield. This solves the task of controlling the process of milking through the technical and technological parameters of rubber.

Milking rubber is constantly exposed to mechanical and physical factors that devastatingly affect its properties [39]. Thus, the purpose of our further study was to establish the level of bacterial insemination of milking rubber over the time of its operation and its effect on the quality of milk. During the research (Table 6), a positive correlation dependence of the levels of bacterial insemination of milking rubber on the received milk (r=+0.984) was found. A slightly lower correlation dependence (r=+0.960) was established of the service life of milking rubber on the level of its bacterial insemination.

The results obtained expand the idea of interaction between the technological indicators of milking rubber and milk so that the task of forecasting the bacterial insemination of products to be received is solved.

Our study testifies that rubber products acquire a wide range of values in terms of the basic technical indicators. This makes it possible to argue that, in order to ensure the optimal implementation of the milking process, it is necessary to pay due attention to the milking rubber – both new and already operated.

The results of our study are consistent with those reported by other authors, performed earlier [10, 15, 22, 40, 41], and complement them. A significant difference in the methodical plan of our study was the opportunity to study not only the rigidity of rubber products but also a series of important technical indicators (coefficient of aging due to tension, relative residual deformation, etc.). At the same time, given the significant variability and differences in the structural parameters of milking rubber, there are certain issues in solving the task of the complete compliance of a rubber product to the physiological needs of the herd. This remains an unresolved issue in the milk production technology link.

One novelty of our study is the introduction of new procedures (investigating changes in the properties of rubber in aggressive working fluids) to estimate the milking rubber, which is in the design stage. This would allow the optimal selection of formulations for the manufacture of a rubber element. At the present stage, washing milking and dairy equipment involves a variety of aggressive means at high temperatures, which adversely affects the rubber.

The knowledge of types and technical characteristics of milking rubber made locally and abroad could make it possible to find an adequate solution when choosing rubber products for milking the herd. This would ensure a constant stereotype of milking, the uniform development of the udder parts, taking into consideration the dynamics of the lactation curve, the udder health, the duration of using cows in the stage, the operation of equipment, and the quality of products.

The results of our study form the basis for designing the optimized variants of milk production technologies, as well as for the construction of devices and methods of quality control over milking rubber.

We find it promising to undertake research aimed at identifying the mechanism that influences the milking rubber of milking cups with a different design (triangular, ventilation, etc.) on the indicators of milking high-performance cows.

7. Conclusions

1. We have established a significant range of milking rubber deflection (from 5.5±0.03 to 3.7±0.04 mm) and the teat cup deformation (from 1.3±0.02 to 3.5±0.05 mm) after 600–650 hours of operation. A positive correlation dependence of the milking rubber elasticity on the deformation of its teat cup ($r=+0.948$) has been derived.

Our study into the integrity of rubber products by passing an electrical discharge has found that 5 % (from a batch of 200 pcs.) of the rubber DD 00.041A made by AT «Agrotechimport» are discarded due to defects. It was established that in terms of the variance coefficient the milking rubber DD 00.041A made by AO «Bratslav» belongs to group I – the quality is considered to be excellent ($\upsilon<10$ %).

2. It was determined that the change in the mass and volume of milking rubber at $t=150$ °C over 72 hours of treatment with the liquid ZHR-3 exceeds, by more than 2.5 times, the indicators obtained in contact with the liquid Skydrol LD-4. A positive correlation dependence of the milking rubber mass on its volume ($r=+0.965$) has been established.

3. At a tension of milking rubber in the range from 0 to 90 N, the duration of the deformation loss by the milking rubber shell is short; it is 0.05–0.06 s.

4. During month 6 of the milking rubber operation, the number of microorganisms per 1 cm^2 of its inner surface increases by 11.9 times; it is 89.4±5.11 thousand CFU at $p<0.001$. It was found that 1 cm^3 of milk hosts 711±24.85 thousand CFU, which is 5.8 times larger than the indicator obtained in the operation of milking rubber during the first month ($p<0.001$).

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