Influence of devices for cleaning the milk pipes of the milking units on the ecology of milk production

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Abstract. The article describes the improved design of a mechanical cleaner that improves the efficiency of the sanitization of a milking unit. The developed devices allow adding to the hydraulic effect of the washing solution the mechanical effect of the foam and bristle cleaning base. A description is given of the design and principle of operation of mechanical cleaners designed and manufactured at the Nizhny Novgorod State Engineering and Economic University with foam and scrubbed cleaning the base. The results show that if spiral holes are added to the structure, the rotation frequency of the structure increases by an average of 30%, and its linear speed decreases by 20%, compared with the previous design. The use of these devices can reduce the emission of detergents and disinfectants and thereby increase the environmental friendliness of milk production.

1. Introduction
Milk is a polydisperse system consisting of a water base (87-89%) and dry matter, represented by proteins (2.8-3.4%), lipids (3.1-4.3%), carbohydrates (4.5-4.7%), mineral and other substances [1].

Consider a fat particle in a protein-lipid membrane (Figure 1). In the process of transporting milk, it is subjected to mechanical and hydraulic stress. As a result of exposure, protein-lipid membranes are

Figure 1. Milk under a microscope at 400x magnification [2].
destroyed, and free fatty particles collide with similar and with the walls of the milking equipment. In a collision, a greasy film forms on the surface of the milking equipment. Due to the hydraulic pressure of the flow, the fatty particles are distributed, compacted, and saturated with calcium and minerals. Thus, a solid white deposit forms on the walls of the container, which is called the milk stone.

Deposits on the walls of dairy equipment are a breeding ground for the microorganisms' development, which leads to an increase in their number not only on the walls but also in milk. An increase in the bacterial number not only reduces the grade of milk but also leads to a reduction in shelf life. Even if the maximum permissible level of bacterial contamination of milk is exceeded once, all produced milk is subject to sanctions in the form of a reduction in its grade or even transfer to non-sorted milk. This fact leads to significant monetary losses for manufacturers.

2. Materials and methods

Existing sanitary rules for the care of milking units and milk utensils, monitoring their sanitary conditions, and sanitary quality of milk. The purpose of sanitary rules is to minimize the level of bacterial contamination of milking installations. Three technological operations exist for the implementation of sanitary rules [3].

The first operation is the preliminary rinsing of the milking units with running warm water to remove milk residues. The second operation is the circulation washing of milking units with a hot solution of a detergent-disinfectant to remove the protein-fat film and disinfection. The third operation is rinsing the milking units with water to remove residues of detergents and disinfectants.

Detergents and disinfectants used for sterile processing of milking equipment allow combining washing and disinfection of equipment in one technological process. The detergent component in such compositions are surfactants, and chlorine-containing substances, iodine-containing preparations, or quaternary ammonium compounds are used as a disinfectant. On average, 0.7 kg of concentrated detergent-disinfectant and 80 liters of water are spent on the preparation of a washing solution for one sanitary treatment of milking equipment. Taking into account three-time milking per year, the consumption of detergents and disinfectants is more than 750 kg per milking unit.

Most of the components of these products are very aggressive to the environment and have a long lifespan. On dairy farms, there is no technological equipment designed to neutralize detergents and disinfectants. Therefore, the spent solution is discharged into the environment, causing irreparable harm to environmental microflora.

As practice shows, the existing system of sanitary processing of milking equipment does not always allow maintaining an acceptable level of bacterial contamination. Particular difficulties in sanitization are caused by milking installations with a long milk line, for example, UDM-200. In such installations, due to the length of the milk line, significant hydraulic and thermal losses occur as a result of which the washing-disinfecting solution loses its effectiveness.

The following scientific approaches have been developed to increase the effectiveness of the washing-disinfecting solution on the inner surface of the milk pipeline:

1. An increase in pressure on the walls due to a change in the movement parameters of the washing solution: the flow velocity and its turbulence [3, 4, 5]. This approach is based on increasing the hydraulic effect of the solution flow on contaminants. For these purposes, various authors have proposed many technical solutions, starting with increasing the productivity and pressure of the pump, ending with mechanical intensifiers of the flow. The most widely used approach is the creation of cork fluid movement. However, it also showed low efficiency on milking installations with a long milk line. Due to the hydraulic resistance at the interface “washing solution-wall,” the tube loses energy and collapses as a result of which it loses its functionality.

2. The increase in temperature of the washing solution. This approach is based on the effect of thermal disinfection. However, as the temperature of the solution increases, heat loss through the walls of the milk line increases. Consequently, the cost of electricity increases sharply with a slight increase in the washing-disinfecting effect. Besides, increasing the temperature of the solution leads to compaction and a decrease in the resource of rubber products.
3. The increase in the circulation time of the washing-disinfecting solution. An increase in the duration of circulation certainly improves the level of bacterial contamination. However, this process proportionally increases the cost of sanitizing the milking unit. Also, the washing and disinfecting action effectiveness of the solution decreases over time due to the chemical reactions occurring in it.

4. The increase in the concentration of the solution. This approach is based on increasing the concentration and aggressiveness of detergents and disinfectants. Each manufacturer sets the concentration level of substances within small limits, and its excess leads not only to cost overruns but also adversely affects the rubber and plastic products of the milking unit. Also, these substances don't lose their strength during the washing process and enter the environment causing harm to it.

5. Increased pressure on the walls due to mechanical stress. Foam wads are traditionally used, which move by the force of vacuum and remove protein-fat deposits from the walls of the milk line. However, this technical solution shows its advantages in terms of removing residual milk. This technical solution is ineffective for removing the film and especially the "milk stone" due to the high speed. To increase the mechanical impact, we have developed a device for cleaning milk pipelines with pneumatic and electric drives [7, 8].

The developed device operates not only translationally, but also rotationally. The peculiarity of this mechanism significantly increases the force acting on the surface of the milking machine. However, as production tests have shown, this design moves with almost the same longitudinal speed. Electric devices have shown high efficiency. However, there is a need to seal the electronics unit. The electric drive is limited in size.

Moreover, an electrically driven device has a much higher cost with a significantly lower resource. As tests have shown, air-operated cleaning devices are the simplest in their design and quite effective. Therefore, further work was to modernize air-operated cleaning devices.

To increase the effectiveness of the impact, we sought to minimize the speed of longitudinal (linear) movement and increase the speed. For this purpose, an improved model of a mechanical cleaner with spiral holes was developed. The holes are designed to reduce the linear movement speed by reducing the pressure difference before and after the device. The holes' spiral shape is designed to increase the torque, which leads to an increase in the rotation frequency. A general view of the advanced mechanical cleaner is shown in Figure 2.

![Figure 2. 3-d model of an advanced mechanical cleaner: a) front view; b) rearview; c) section](image)

Pollution on the walls of the milk pipeline is presented in two phases (soft grease film and substantial mineral deposits in the form of a “milk stone”). In connection with this circumstance, two versions of the cleaning base were developed, namely, a foam base and a bristle base.

The results of previous studies have shown the effectiveness of using mechanical cleaners with a bristly base for cleaning from a greasy film (Figure 3a). Their effectiveness is because they cut the protein-fat film, thereby increasing the hydraulic and chemical effects of the washing solution [8].

However, in the case of mineralized contamination, the bristles cannot cut through the hard layer,
due to which its cleaning ability is reduced. “Milk stone” is traditional mineralized contamination of the milk milking machine. For the purification of the milk pipeline from such contaminants, as well as for the removal of milk residues, mechanical foam-based cleaners have shown greater efficiency (Figure 3 b).

![Mechanical cleaners with a bristly cleaning base (a) and a foam rubber cleaning base (b)](image)

**Figure 3.** Mechanical cleaners with a bristly cleaning base (a) and a foam rubber cleaning base (b)

Production tests of mechanical cleaners were carried out based on the Polanes 80 milking machine equipped with an Aquarus 50 washing machine, owned by SEC Zarya, Pilninsky District, Nizhny Novgorod Region for determining the motion parameters of the improved design.

The controlled parameters were: linear speed and speed of the mechanical cleaner.

Step-by-step regulation of the vacuum value was carried out employing an installed vacuum regulator for determining the motion parameters at various washing modes.

The vacuum value varied from 5 to 70 kPa and was controlled by a vacuum gauge. The absolute measurement error was ± 0.5 kPa.

![Glass tube marked with a marking](image)

**Figure 4.** Glass tube marked with a marking

For the determination of the controlled parameters, a glass tube was installed at the exit of the milk line with the markings previously applied to it (Figure 4). The distance between the markings was 100 mm.

For the determination of the motion parameters, a video camera was fixed in front of the tube, which recorded in 1080p 60 fps format. The processing of the recorded video was carried out in the program Adobe After Effect 16.1. Based on the results of the resulting video storyboard, the transit time and the number of revolutions in the control segment were determined.
3. The study of the structure of the modified lead-tin-base bronze

As a result, the following results were obtained, presented in Table 1.

Table 1. The results of the study of the dependence of the linear speed and speed of the cleaning device on the vacuum pressure

| №  | Vacuum pressure, kPa | Cleaning device rotation frequency, min⁻¹ | Linear speed of the cleaning device, m / s |
|----|---------------------|-------------------------------------------|-------------------------------------------|
|    | standard            | foam rubber                               | stubble                                   |
| 1  | 5                   | 210                                       | 168                                       | 0,008                                    | 0,0064 | 0,006 |
| 2  | 10                  | 207                                       | 220                                       | 242                                       | 0,016  | 0,0128 | 0,012 |
| 3  | 15                  | 204                                       | 234,6                                     | 252                                       | 0,024  | 0,0192 | 0,018 |
| 4  | 20                  | 198                                       | 236                                       | 259                                       | 0,032  | 0,0256 | 0,024 |
| 5  | 25                  | 175                                       | 211                                       | 253                                       | 0,04   | 0,032  | 0,03  |
| 6  | 30                  | 154                                       | 189                                       | 222                                       | 0,048  | 0,0384 | 0,036 |
| 7  | 35                  | 119                                       | 154                                       | 195                                       | 0,056  | 0,0448 | 0,042 |
| 8  | 40                  | 83                                        | 112                                       | 132                                       | 0,064  | 0,0512 | 0,048 |
| 9  | 45                  | 40                                        | 79                                        | 84,2                                      | 0,072  | 0,0576 | 0,054 |
| 10 | 50                  | 0                                         | 59                                        | 65                                        | 0,08   | 0,064  | 0,06  |
| 11 | 55                  | 0                                         | 24                                        | 42                                        | 0,088  | 0,0704 | 0,066 |
| 12 | 60                  | 0                                         | 13                                        | 29,5                                      | 0,096  | 0,0768 | 0,072 |
| 13 | 65                  | 0                                         | 11                                        | 24                                        | 0,104  | 0,0832 | 0,078 |
| 14 | 70                  | 0                                         | 10                                        | 22                                        | 0,112  | 0,0896 | 0,084 |

Figure 5. Graph of linear velocity and frequency of rotational motion versus vacuum gauge pressure

Based on the results obtained, a graph was plotted of the linear velocity and frequency of rotational motion as a function of vacuum pressure (Figure 5).

The optimal vacuum value for the device of the previous design (on the IF graph) is 20 kPa [8]. However, with this value, the hydraulic effect of the washing solution is not sufficient, and with an increase in a wad, it sharply reduces the speed and changes only to linear motion. Improved mechanical cleaners due to the presence of spiral holes allow increasing the vacuum to 30-35 kPa at the same speed, which leads to an increase in the washing solution speed and an increase in the flow turbulence.

According to the results of Matveev studies [8], the use of mechanical cleaners of the previous design allows reducing the volume of the washing solution by 30% compared to traditional washing
technology. The savings is 230 kg of detergent and disinfectant and 26 m$^3$ of water per year. The improved design of the cleaner due to the increase in mechanical stress should show better results. Additional tests are planned for confirming theoretical assumptions.

4. Conclusion
Thus, the devices developed at the Nizhny Novgorod State Engineering and Economic University allow achieving the following results:

1. To reduce the cost of sanitization of milking machines by reducing the complexity, consumption of electricity, water, and detergents.
2. As a result of adding spiral holes to the design, the rotational speed increases by an average of 30%, and the linear speed decreases by 20%, compared with the previous design.
3. To reduce emissions of detergents and disinfectants, thereby increasing the environmental friendliness of milk production.

However, to increase the intensity of cleaning, synchronization with a washing machine, and the possibility of supplying several mechanical cleaners, it is necessary to develop a device for their supply.

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