

The application of techniques for effective cleaning of milking routes in milking machines is an important way to improve the quality of milk and increase labor productivity in dairy farming.

The object of research was the system of washing the milk line of the milking machine with the upper milk line.

The problem of rational use of energy resources was solved in the implementation of a routine operation – washing the milking machine.

Experimental studies were carried out according to the Box-Benkin plan of the second order for 3 factors (the speed of movement of the washing solution, V ; the temperature of the washing solution, T ; the duration of the rinsing phase, t). In this case, a mathematical apparatus for planning a multivariate experiment according to the D-optimal plan was used.

It was found that with an increase in the speed of movement of the washing solution and temperature, as well as the duration of the rinsing phase, the number of microorganisms on the surfaces of the nodes and elements of the milky line decreases. Milk lines of the milking machine made of any material are better cleaned with a hotter washing solution ($40\text{ }^{\circ}\text{C}$) than with a cold one ($20\text{ }^{\circ}\text{C}$). Thus, when cleaning with a solution of $40\text{ }^{\circ}\text{C}$ of stainless steel and food aluminum, the reduction of microorganisms is 4.3 times, glass – 4 times, and rubber – 4.7.

The essence of the experiment was to establish patterns when cleaning the milk line from various materials.

The influence of the regime parameters (the speed of movement of the washing solution, V ; its temperature, T ; and the duration of the rinsing phase, t) on the energy consumption of the milking machine, E , was determined.

The compromise problem of rationalizing the washing modes of the milk lines of the milking machine has been solved. Thus, rational mode parameters for the washing system were established: $V=2.4\text{ m/s}$, $T=38.2\text{ }^{\circ}\text{C}$, $t=3.2\text{ minutes}$. With these parameters, the optimization criteria are: $N=79\text{ thousand CFU/cm}^3$, $Q=23.3\text{ l}$, $E=8.08\text{ kWh}$

Keywords: milking equipment, cleaning process, washing the milk line, water flow rate, energy consumption

UDC 631.3.636

DOI: 10.15587/1729-4061.2022.265778

DETERMINING THE EFFECTIVE MODE OF OPERATION FOR THE SYSTEM OF WASHING THE MILKING MACHINE MILK SUPPLY LINE

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Received date 12.07.2022

Accepted date 30.09.2022

Published date 31.10.2022

How to Cite: Paliy, A., Aliiev, E., Paliy, A., Kotko, Y., Kolinchuk, R., Livoschenko, E., Chekan, O., Nazarenko, S., Livoschenko, L., Uskova, L. (2022). Determining the effective mode of operation for the system of washing the milking machine milk supply line. *Eastern-European Journal of Enterprise Technologies*, 5 (1 (119)), 74–81. doi: <https://doi.org/10.15587/1729-4061.2022.265778>

1. Introduction

The quality of milk and the safety of its consumption largely depend on the purity and sterility of milking and dairy

equipment. In the case of insufficient cleaning and disinfection of the inner surface of milking equipment, milk residues accumulate on it within a short period of time. They are a good nutrient medium for the development of microorganisms.

Thus, lactic acid bacteria on similar media double their number in an average of 40 minutes, bacteria of the *Escherichia coli* group – in 20 minutes at 30 °C. That is, under ideal conditions in the period between milking cycles, the number of microflora increases by about 16400 times. Bacteria remaining after disinfection in the amount of 2 % among lipid protein contaminants can restore their numbers in about 3.5 hours [1–3].

At present, the production of high-quality milk is considered relevant with the use of modern technical and technological means and methods for the care of milking and dairy equipment [4].

In addition, one of the topical issues is the lack of information on modern engineering solutions in cleaning milking and dairy equipment from contamination. This issue is an important component of the problem of improving the quality of milk and eliminating product losses.

Thus, the need for studies is related to establishing the effectiveness of the use of engineering solutions in cleaning milking equipment from contamination. This approach will make it possible to carry out effective cleaning of milking systems of milking equipment. That will significantly increase the productivity of milking equipment and the quality of the milk produced.

Therefore, studies aimed at determining the effective mode of operation of the milk line washing system of the milking machine are relevant.

2. Literature review and problem statement

The development of dairy farming led to the saturation of dairy complexes with milking and dairy equipment, which significantly lengthened the path of milk from the milking of the cow's udder to the tank for harvesting and storage. Milk from cows' teats during machine milking is almost sterile. Passing through the milking systems of the milking machine, the milk is in contact with the inner surface, the area of which is more than 25 m². In this case, protein-fat biofilms of contaminants are formed, which is an excellent environment for the development of microorganisms. With insufficiently effective cleaning of these contaminants, in the periods between milking cycles, the number of microflora increases tens of thousands of times. With further milking, the main part of the microflora of developed contaminants enters the milk, significantly worsening the indicators of its sanitary and hygienic quality [5].

Thus, as indicated in [6], the main task of the technological process of washing the equipment is to properly clean the milking equipment after use with an effective combination of the main factors.

As noted in [7], the time of circulation washing depends on the type of washing solution, dosage, degree of contamination, and efficiency of mechanical action. As a rule, this time is about 10 minutes if a combined solution (washing and disinfectant) is used, or 7–8 minutes for circulating washing with a washing solution and 5 minutes of disinfection. Thus, the specific time of mechanical action is not defined. Along with this, the issue of using specific washing solutions has not been considered.

In [8], it is noted that the temperature of the washing solution at the beginning of circulation washing should be 70–90 °C and should not be lower than 40 °C at the end of circulation washing. Maintaining the temperature of the solution above 40 °C is necessary so that the dirt, and especially fat, remains dissolved in water and does not settle on the walls of the milk line again. However, with insufficient

disclosure of the issue of the use of washing solutions, the mechanism of influence on pollution is not fully disclosed.

Along with this, it is noted in work [9] that in no case should the milking equipment be washed immediately with hot water. Given this, the remnants of settled organic substances that accumulate on the walls of the parts later form the so-called «milk stone». At the same time, this statement needs clarification in terms of identifying the mechanism of interaction of hot water with pollution.

Studies [10] into the indicators of the technological mode of washing are ambiguous. At the same time, a number of recommended parameter values cannot be obtained, or are unacceptable when servicing milking equipment. Therefore, the washing modes of the milk line and the parameters of the equipment for this need to be justified.

In most cases, milk production is associated with a high consumption of electricity, labor, and solutions due to the fact that milking equipment must be washed and disinfected after each use. It is important to reduce the time of these operations, combining them and, at the same time, maintaining efficiency, thereby reducing the cost of electricity, water, and washing solutions. It is economically appropriate to use modern washing disinfectants and establish for them reasonable modes of sanitization of milking equipment under the conditions of a particular dairy unit [11]. Therefore, the application of techniques for effective cleaning of milking routes of milking machines is an important way to improve the quality of milk and increase productivity in dairy farming.

Thus, solving the problem of improving the sanitary and hygienic quality of the milk produced requires research, refinement, and improvement of technical means for servicing milking and dairy equipment. This is of both scientific and practical interest.

3. The aim and objectives of the study

The purpose of this study is to determine the effective mode of operation of the milk line washing system of the milking machine. This will improve the quality of the products and the productivity of milking equipment.

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

- to investigate various modes of washing the milk lines of the milking machine from the point of view of determining the rational mode of operation of the system;

- to determine the water flow rate and energy consumption for different modes of washing the milk lines of the milking machine;

- to solve the compromise problem of rationalizing the washing modes of the milk lines of the milking machine.

4. The study materials and methods

The object of this research was the system of washing the milk line of the milking machine. It was hypothesized that the effective mode of operation of the milk line washing system of the milking machine can be determined by the establishment and optimization of its regime parameters.

Studies into the modes of cleaning milking systems from contamination were carried out at the laboratory bench of a milking machine with an upper milk line with the washing apparatus produced by TDV «Bratslav» (Ukraine). The general view of the laboratory bench is shown in Fig. 1.

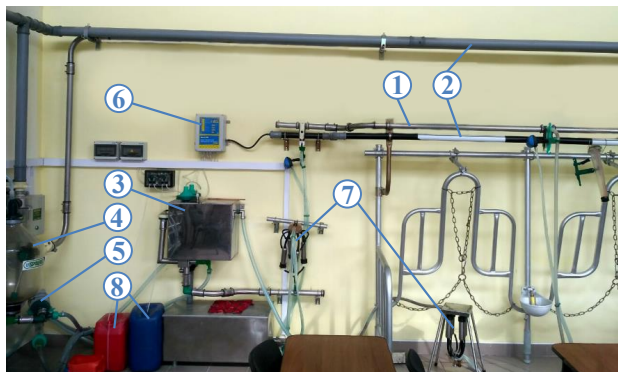


Fig. 1. Laboratory bench of the milking machine with an upper milk line with the BUAP-03 washing apparatus manufactured by TDV «Bratslav»: 1 – milking line, 2 – vacuum line, 3 – tank with a washing solution, 4 – milk collector, 5 – milk pump, 6 – washing process control unit, 7 – milking machine, 8 – tanks for washing solutions

Before the start of each experiment, 150 liters of raw milk were pumped through the milk line (according to DSTU 3662:2018. Cow’s raw milk). Due to the limited amount of milk available, 30 liters of milk were actually pumped 5 times. This number is taken for reasons of using a laboratory milking machine, that is, a part of a full-fledged one with 1 milking machine and a milk-conducting line of 9 m. Milking machine of the UDA-8 type is designed for 100 heads. The average milk yield of a cow per milking is 11–13 liters. Therefore, 1 milking machine accounts for $100 \times 12 / 8 = 150$ liters.

The number of mesophilic aerobic and facultative-anaerobic microorganisms (at a temperature of 30 °C) in it exceeded 2000 thousand CFU/cm³. Thus, the contamination of the milk line was simulated. We counted the number of mesophilic aerobic and facultative-anaerobic microorganisms using DSTU 7089:2009.

The device BUAP-03 performs three programs for washing milking systems: pre-milking, washing (post-milk washing), and disinfection.

During the execution of each of these programs, an appropriate sequence of phases is fulfilled. Thus, there are six phases of washing (identified by serial numbers from 1 to 6). Phase No. 1 is used only during the implementation of the pre-milking washing program. Phases No. 2, No. 3, and No. 4 are executed during the post-milking cleaning program. Phases No. 2–6 are performed during the disinfection program.

The composition of each phase includes subphases. The algorithm for performing a subphase depends on the program and the phase number, which includes the subphase [12].

The process of cleaning the test milk line from contamination included the phases of preliminary rinsing with cold water to wash off milk residues, circulating cleaning (disinfection) with solutions of washing synthetic powders and disinfectants, and final rinsing from residues of the washing solution. The aforementioned subphases have been included in the studies in the main phases.

As a fixed mode of washing, parameters given in Table 1 were taken.

The surfaces of the components and elements of the milk line, which were made of food stainless steel, glass, polyethylene, rubber, and food aluminum, were investigated.

The speed of movement of the washing solution *V* was changed by changing the vacuum value in the vacuum circuit. This was enabled by changing the rotational speed of the

asynchronous motor of the vacuum unit using a frequency converter. The value of the speed of movement of the washing solution was controlled using a water flow sensor by appropriate recalculation; it was 2 m/s, 4 m/s, 6 m/s.

Table 1
Fixed parameters of the washing process that are configured in BUAP-03

No.	Parameter name	Value, s
1	Duration of water absorption during pulsation	10
2	Duration of air suction during pulsation	5
3	The duration of the pause during pulsation	5
4	The duration of the pause during the tank emptying subphase	10
5	Duration of air supply during the drying subphase	5
6	Duration of the rinsing subphase	varied
7	The duration of the subphase of circulation washing with detergent	1200
8	Duration of activation of the dosing device for detergents and disinfectants	8
9	The duration of the subphase of circulation washing with a disinfectant	1200
10	Duration of the drying subphase	180
11	The duration of the pause during the drying subphase	20
12	Duration of water suction during the tank emptying subphase	30
13	Duration of tank filling management by the upper level during circulation flushing	0
14	The delay of the start of pulsation after switching on the vacuum pump at the beginning of the program	15

The temperature of the washing solution *T* was set using a boiler: it was 20 °C, 30 °C, 40 °C. Washing solution was applied through a valve into the tank.

The duration of the rinsing phase *t* was set using a change in the operating modes of the washing process control unit and was 2 minutes, 4 minutes, 6 minutes. The duration of each subphase was measured by a unit, and the result was displayed on the unit’s indicator.

The criterion for assessing the quality of the washing process is the number of mesophilic aerobic and facultative-anaerobic microorganisms on the surfaces of the nodes and elements of the milk line *N*. The number of mesophilic aerobic and facultative-anaerobic microorganisms was determined at a certified laboratory in accordance with DSTU ISO 4833:2006 (relative measurement error, 5 %).

A flow-through water meter NOVATOR LK-15X was installed to the water supply system with a measurement error of ±1. Using the specified meter, water flow rate *Q* for each washing cycle was established.

To estimate the energy consumption *E* of the milking machine during washing, the values of the three-phase electric meter NIK2303 AR3T.1000.M.11 (measurement error, ±0.01 kWh) were recorded. The meter was installed in front of all loads of the milking plant (electric motors, heaters, electronic control units, etc.).

Experimental studies were carried out according to the Box-Benkin plan of the second order for 3 factors (the speed of movement of the washing solution, *V*; the temperature of the washing solution, *T*; the duration of the rinsing phase, *t*). In this case, a mathematical apparatus for planning a mul-

tivariate experiment according to the D-optimal plan was used, which involves the coding of factors (Table 2).

Table 2

Limits and levels of variation by research factors

Factor variation level	The speed of movement of the washing solution V , m/s	Temperature of the washing solution T , °C	Duration of the rinsing phase t , min
Notation in coded form	x_1	x_2	x_3
Lower ($x=-1$)	2	20	2
Middle ($x=0$)	4	30	4
Upper ($x=1$)	6	40	6

Using the Wolfram Mathematica 12.3 software package (Wolfram Research, USA) involving the «Fit» function, the corresponding regression equations of evaluation criteria from research factors in encoded form were built (Official company website Maple – Software developer Maple 9. – [Electronic resource]. – Access mode: <http://www.maplesoft.com> (Serial Number IS: 917995808). (Eng).

5. Results of determining the effective mode of operation of the milk line washing system of the milking machine

5.1. Investigation of various modes of washing the milk lines of the milking machine in terms of determining the rational mode of operation of the system

According to the results of experimental studies, a mathematical model of the influence of the studied factors on the efficiency of machine washing of a stainless steel milk line was built.

The influence of research factors on the number of mesophilic aerobic and facultative-anaerobic microorganisms on the surfaces of nodes and elements of the milk line N in the form of a regression equation in coded form is:

$$N = 176.267 + 39.175x_1 - 0.208333x_1^2 - 99.325x_2 + 0.45x_1x_2 + 0.991667x_2^2 - 40.45x_3 + 0.3x_2x_3 + 0.241667x_3^2. \tag{1}$$

At the 95 % confidence level for equation (1), the variances are homogeneous, and the values of the Cochran criterion $G=0.1515 < G_{0.05}(2, 15)=0.3346$.

The variance of the adequacy of the regression equation $S_{ad}=8.305$; the variance of error $S_y=5.373$; Fisher’s criterion $F=1.54 < F_{0.05}(11, 30)=2.13$; the model is adequate.

According to Student’s criterion, the coefficients for the following terms of the regression equation are significant: x_1, x_2, x_3 .

According to the above, the regression equation (1) is:

$$N = 176.267 + 39.175x_1 - 99.325x_2 - 40.45x_3. \tag{2}$$

In decoded form, model (2) takes the following form:

$$N = 476.792 - 20.225t - 9.9325T + 19.5875V, \tag{3}$$

where N is the number of mesophilic aerobic and facultative-anaerobic microorganisms, thousand CFU/cm³, V is the speed of movement of the washing solution, m/s; T is the temperature of the washing solution, °C; t is the duration of the rinsing phase, min.

Dependence plots for equation (3) are shown in Fig. 2–4.

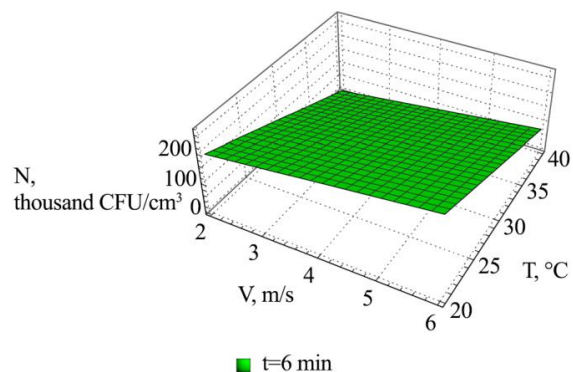


Fig. 2. Dependence of the number of mesophilic aerobic and facultative-anaerobic microorganisms N on the surfaces of the nodes and elements of the milk line on the speed of movement of the washing solution V and the temperature of the washing solution T

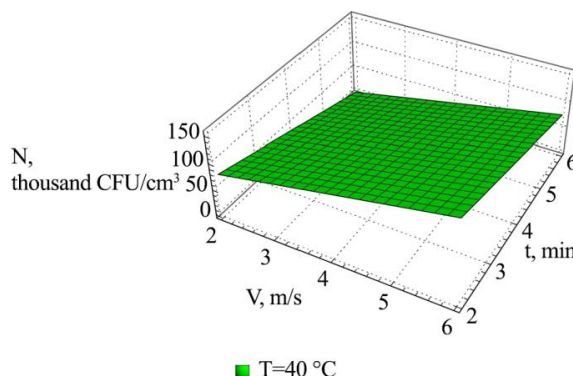


Fig. 3. Dependence of the number of mesophilic aerobic and facultative-anaerobic microorganisms N on the surfaces of the nodes and elements of the milk line on the speed of movement of the washing solution V and the duration of the rinsing phase t

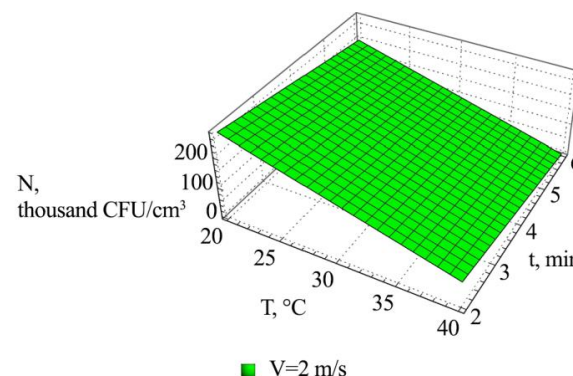


Fig. 4. Dependence of the number of mesophilic aerobic and facultative-anaerobic microorganisms N on the surfaces of the nodes and elements of the milk line on the temperature of the washing solution T and the duration of the rinsing phase t

It was found that with an increase in the speed of movement of the washing solution and temperature (Fig. 2), phase duration (up to 6 minutes) (Fig. 3), the number of microorganisms on the surfaces of the nodes and elements of the milk line decreases.

It was established that the number of mesophilic aerobic and facultative-anaerobic microorganisms on the surfaces of the nodes and elements of the milk line N depends on the material from which they are made (Table 3).

Table 3

The dependence of the number of microorganisms on different materials of the milk line on the water temperature of preliminary rinsing

Material	Water temperature, °C	Number of mesophilic aerobic and facultative-anaerobic microorganisms on surfaces N , thousand CFU/cm ³
Stainless steel	20	260±3
	30	161±2
	40	61±1
Glass, polyethylene	20	221±3
	30	122±2
	40	56±1
Rubber	20	360±3
	30	186±2
	40	76±1
Food aluminum	20	304±3
	30	172±2
	40	70±1

With an increase in water temperature, significant changes in the duration of rinsing of the milk line to good quality, no removal of proteins without their destruction was observed.

It was found that with an increase in water temperature to 40 °C, compared with 20 °C, the number of microorganisms decreases significantly during preliminary rinsing. Thus, when cleaning stainless steel and food aluminum, the reduction of microorganisms is 4.3 times, glass – 4 times, and rubber – 4.7.

This indicates the need to use water at a temperature of at least 40 °C when pre-rinsing the milk line.

The parts and components of the milk line made of rubber (milking rubber of milking machines and milk hoses) and food aluminum (milk chamber of the collector, parts of the means of accounting for milk yield, etc.) are worse rinsed. However, as a rule, they have a cross-section much smaller than the milk line itself. In this regard, the speed of water flow when washing parts made of these materials is always higher than the speed in the milk pipe. This allows the selection of pre-rinsing modes based on the materials of the milk duct.

5. 2. Determining the water flow rate and energy consumption for different modes of washing the milk lines of the milking machine

The influence of research factors on water flow rate Q for each washing in the form of a regression equation in encoded form is:

$$Q = 33.521 + 9.78134x_1 - 0.104167x_1^2 + 0.3375x_2 + 0.225x_1x_2 + 0.495833x_2^2 + 9.96884x_3 + 5.09692x_1x_3 + 0.15x_2x_3 + 0.120833x_3^2. \tag{4}$$

At the 95 % confidence level for equation (4), the variances are homogeneous, and the values of the Cochran criterion $G=0.1515 < G_{0.05}(2, 15)=0.3346$.

The variance of the adequacy of the regression equation $S_{ad}=2.326$; the variance of error $S_y=1.343$; Fisher's criterion $F=1.73 < F_{0.05}(11, 30)=2.13$; the model is adequate.

According to Student's criterion, the coefficients for the following terms of the regression equation are significant: x_1, x_3, x_1x_3 .

According to the above, regression equation (4) takes the following form:

$$Q = 33.521 + 9.78134x_1 + 9.96884x_3 + 5.09692x_1x_3. \tag{5}$$

In decoded form, model (2) takes the following form:

$$Q = 14.4083 - 0.20625V + t(-0.1125 + 1.27423V), \tag{6}$$

where Q is the water flow rate for each washing cycle, l. Dependence plot for equation (6) is shown in Fig. 5.

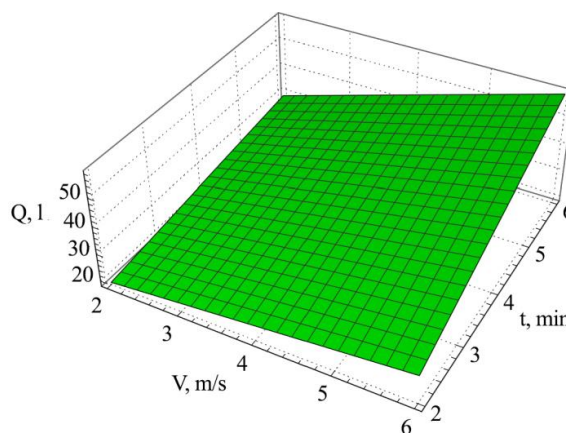


Fig. 5. Dependence of water flow rate Q for each washing on the temperature of the washing solution T and the duration of the rinsing phase t

The influence of research factors on the energy consumption E of the milking machine during washing in the form of a regression equation in encoded form is:

$$E = 10.1167 + 0.73125x_1 - 0.214583x_1^2 + 0.45625x_2 + 0.0375x_1x_2 - 0.114583x_2^2 + 4.5625x_3 + 0.4x_1x_3 + 0.225x_2x_3 - 0.177083x_3^2. \tag{7}$$

At a 95 % confidence level for equation (7), the variances are homogeneous, and the values of the Cochran criterion $G=0.1543 < G_{0.05}(2, 15)=0.3346$. Variance of adequacy of the regression equation $S_{ad}=0.964$; error variance $S_y=0.616$; Fisher's criterion $F=1.56 < F_{0.05}(11, 30)=2.13$; the model is adequate.

According to Student's criterion, the coefficients for the following terms of the regression equation are significant: x_1, x_2, x_3 .

According to the above, regression equation (7) is:

$$E = 10.1167 + 0.73125x_1 + 0.45625x_2^2 + 4.5625x_3. \tag{8}$$

In decoded form, model (2) takes the following form:

$$E = -1.83958 + 2.28125t + 0.045625T + 0.365625V, \tag{9}$$

where E is the energy consumption of the milking machine during washing, kWh.

Dependence plots for equation (9) are shown in Fig. 6–8.

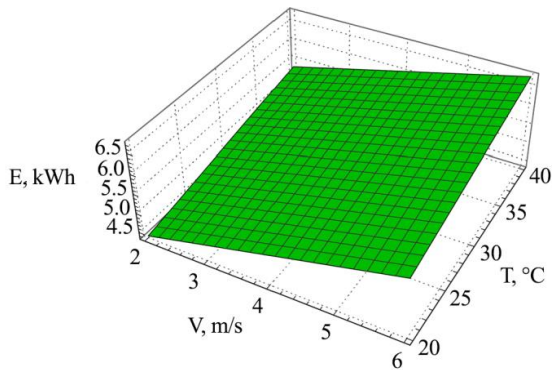


Fig. 6. Dependence of the energy consumption of the milking machine during washing E on the speed of movement of the washing solution V and the temperature of the washing solution T

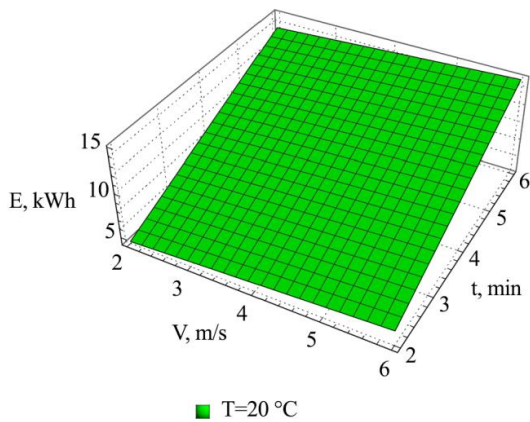


Fig. 7. Dependence of the energy consumption of the milking machine during washing E on the speed of movement of the washing solution V and the duration of the rinsing phase t

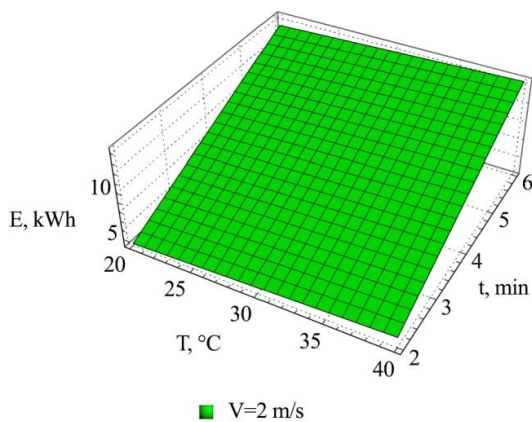


Fig. 8. Dependence of the energy consumption of the milking machine during washing E on the temperature of the washing solution T and the duration of the rinsing phase t

Thus, as a result of research, the quantitative parameters of the washing system have been determined. Thus, the influence of the regime parameters (the speed of movement of the washing solution, V ; its temperature, T ; and the duration

of the rinsing phase, t) on the energy consumption of the milking machine E has been determined.

5.3. Solving the compromise problem of rationalizing the washing modes of the milk lines of the milking machine

Due to the fact that for each criterion for evaluating the experiment, the optimal values of factors that do not coincide are determined, a compromise problem has been solved, which takes the following form:

$$\begin{cases} N(V, T, t) \rightarrow \min, \\ Q(V, T, t) \rightarrow \min, \\ E(V, T, t) \rightarrow \min. \end{cases} \quad (10)$$

Problem (10) is solved by the method of scalar ranking by minimizing the multiplicative function taking into consideration the importance coefficient of the special criterion:

$$\frac{N}{\max(N)} \frac{Q}{\max(Q)} \frac{E}{\max(E)} \rightarrow \min, \quad (11)$$

where min is the minimum value of the function.

Solving in the Wolfram Mathematica 12.3 software package (Wolfram Research, USA) [13] equations (11) together with (3), (6) and (9), the rational mode parameters of the washing system were obtained: $V=2.4$ m/s, $T=38.2$ °C, $t=3.2$ minutes. With these parameters, the optimization criteria were $N=79$ thousand CFU/cm³, $Q=23.3$ l, $E=8.08$ kWh.

6. Discussion of results of determining the effective mode of operation of the milk line washing system of the milking machine

The analysis of the experiments [14–16] shows that cleaning the milk line of the milking machine from the existing contamination significantly affects the quality of the products and the productivity of milking and dairy equipment.

At the initial stage of research, the goal was to investigate the effectiveness of various modes of washing the milk lines of the milking machine. During the research, an original procedure was used, which provided for the use of a laboratory bench of a milking machine with an upper milk line (Fig. 1). According to the results of the studies, plots were constructed of the dependence of the number of mesophilic aerobic and facultative-anaerobic microorganisms (thousand CFU/cm³) on the speed of movement of the washing solution (m/s), its temperature (°C), and the duration of the rinsing phase (min.) (Fig. 2–4).

Our results of the effectiveness of various modes of washing of the milking machine reveal the mechanism of interaction of the regime parameters of washing the milk line on microorganisms remaining on the surfaces of the milk lines. Given this, the problem is solved on the rational selection of regime parameters – the speed of movement of the washing solution, temperature, and duration of the phase of the process.

Along with this, it was established that the number of mesophilic aerobic and facultative-anaerobic microorganisms on the surfaces of the nodes and elements of the milk-conducting line depends on the material from which they are made (Table 3).

In [17, 18], it is noted that the efficiency of washing the milk line is significantly influenced by the material from which the milk line is made. The advantages of our research over the above-mentioned ones are the identification of

temperature differences in the cleaning of elements of milking equipment made of various materials.

At the next stage, water flow rate and energy consumption were determined for various modes of washing the milk lines of the milking machine. Figure 5 shows the dependence of water consumption for each washing cycle on the temperature of the washing solution and the duration of the rinsing phase. Our results regarding the energy consumption during the maintenance of dairy equipment expand the understanding of the process of cleaning the milk line taking into account water consumption, which is currently relevant.

According to the results of the research, dependence plots of the energy consumption of the milking machine during washing (kWh) on the speed of movement of the washing solution (m/s), its temperature (°C), and the duration of the rinsing phase (min.) were constructed (Fig. 6–8).

In [19], attention is focused on the fact that the process of cleaning the milk line is energy-consuming. Our studies confirm this theory and make it possible to critically approach the issue of technical and technological maintenance of milking and dairy equipment.

Subsequently, we solved the compromise problem of rationalizing the washing modes of the milk lines of the milking machine. Thus, solving equations (11) in the Mathematica software package together with (3), (6), and (9), rational mode parameters of the washing system are obtained.

Our studies are distinguished among others [20–22] by a comprehensive approach, as well as the use of innovative equipment. Along with this, due to the extremely significant variability of the structural materials of the milking line of the milking machine, there are difficulties in solving the issue of complete cleaning from contamination. This remains a problematic part of the overall technological process of obtaining high-quality milk.

The results of our research are consistent with the research carried out earlier in the field of development of technical and technological means and technologies for dairy cattle breeding [23–25], complementing them. A significant difference in the methodological plan of the conducted research was that the parameters that affect the efficiency of cleaning the milk line of the milking plant made of different materials were taken into account as much as possible. This created an opportunity to study and substantiate the optimal mode parameters for cleaning dairy equipment.

With a large range of means for cleaning the milk line of the milking machine, it becomes necessary to conduct further research in the field of choosing cleaning preparations. Therefore, studies aimed at establishing the mechanism of interaction of the elements of the milk line with washing solutions and disinfectants are considered promising, which will make it possible to expand the area of both theoretical and practical knowledge in dairy cattle breeding, which will serve as a prerequisite for the rational use of milking and dairy equipment.

7. Conclusions

1. It was found that with an increase in the speed of movement of the washing solution and temperature, as well as the duration of the rinsing phase, the number of microorganisms on the surfaces of the nodes and elements of the milky line decreases. Milk lines of the milking machine made of any material are better cleaned with a hotter washing solution (40 °C) than with a cold one (20 °C). Thus, when cleaning with a solution of 40 °C of stainless steel and food aluminum, the reduction of microorganisms is 4.3 times, glass – 4 times, rubber – 4.7.

2. The influence of the regime parameters (the speed of movement of the washing solution V , its temperature T , and the duration of the rinsing phase t) on the energy consumption of the milking machine E was determined. Thus, with an increase in the regime parameters, the energy consumption E increases directly proportionally.

3. Rational mode parameters for the washing system were established: $V=2.4$ m/s, $T=38.2$ °C, $t=3.2$ min. With these parameters, the values of the initial variables that were minimized are equal to: $N=79$ thousand CFU/cm³, $Q=23.3$ l, $E=8.08$ kWh.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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