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ЗМІСТ

CONTENTS

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EXPERIMENTAL STUDIES OF THE STAND OF THE AUTOMATED MILKING UNIT WASHING SYSTEM WITH AIR INJECTORS AND A PHOTO SENSOR FOR DETERMINING THE CONTAMINATION LEVEL

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One of the key indicators of the quality of milk used for further processing is the level of bacterial contamination. This parameter directly depends on the sanitary and hygienic maintenance of milking equipment, the speed of milk cooling and the influence of other external factors.

During milking, milk passes through various elements of the system, such as milking machines, milk pipes, milk collectors, individual and group meters, etc. These elements can become sources of bacterial contamination. To improve the quality of milk, it is recommended to increase the efficiency of washing milking units, which includes extending the duration of washing. However, this leads to an increase in operational costs (water, detergents, electricity, etc.) and, accordingly, the cost of dairy products.

Over time, deposits of an alkaline and acidic nature are formed on the inner surfaces of the milk ducts, which differ in composition, properties and strength of adhesion to the surface. This contamination leads to bacterial contamination of milk, which reduces its quality and shelf life [1].

To improve the quality of washing, it was proposed to use an injector that periodically supplies air to the milk line. This creates significant fluctuations in vacuum pressure, which, in turn, causes controlled hydraulic shocks. This process should be managed by automated milking equipment systems.

The quality of the flushing system is difficult to assess and control without special sensors and devices for measuring the contamination of the milk duct [2]. The purpose of the study is to conduct experimental tests of the operating modes of the air injector of the milk duct washing system and determine its optimal parameters. It is also planned to develop equipment for automatic detection of contamination of the milk duct during washing.

In experimental studies, the dependences between the rate of pressure change and the level of cleanliness of the milk duct, as well as between the working vacuum pressure, the volume flow of air through the injector, the duration of air intake and the duration of the pause were found. In order to achieve a compromise, which consists in minimizing the rate of pressure change at the maximum level of cleanliness of the milk duct, the optimal parameters of the injector operating modes were determined. The expediency of using the developed equipment for automatic control of contamination of the milk duct during washing is shown. The dependence of the thickness of the layer of milk moving in the glass tube on the resistance of the photoresistor, which is affected by the light partially absorbed by the milk, is also established.

Key words: *milking unit, washing system, injector, parameters, experimental studies, frequency step, washing solution, photo sensor, contamination, milk line.*

Eq. 19. Fig. 9. Table. 4. Ref. 16.

1. Problem formulation

During the operation of milking units, various deposits accumulate on the internal surfaces of pipelines, differing in composition, properties, thickness and strength of adhesion to the cleaned surface. This leads to contamination of milk, which, in turn, reduces its quality and cost of sale. A significant part of microbial and mechanical contamination of milk occurs due to insufficient washing of milking and milking equipment, even if all the conditions of keeping livestock premises are observed. Therefore, the effectiveness of the washing process is an important technological operation on which the level of primary milk contamination depends.

Among the indicators of milk quality that determine its technological properties for further processing, bacterial contamination is the most critical. This indicator mainly depends on two external factors: the sanitary condition of the milking equipment and the efficiency of milk cooling. The milk that comes from the cow's udder passes through milking machines, a milk duct and a milk collector. If the sanitary condition of the milking equipment is unsatisfactory, further cooling of contaminated milk will not provide the desired result. Therefore, the introduction of modern methods of effective cleaning of milk ducts of milking plants is key to improving the quality of milk.

2. Analysis of recent research and publications

Analysis of washing systems [3] revealed several main trends in the development of automatic washing machines: the transition from systems with small capacities to larger tanks; transition from unprogrammed to programmed systems; introduction of crustal flow of washing liquid and heating of washing systems. At the current stage of development of milking equipment, programmable flushing systems are the most promising, as they can be adapted to different configurations of milking units [4].

To improve the quality of washing, it is suggested to use an injector that provides periodic air supply to the milk line, while creating significant fluctuations in vacuum pressure and, as a result, controlled water hammers. Management of this process should be carried out with the help of automated systems of milking equipment [4].

Experimental studies were carried out on a specially designed stand created on a laboratory milking plant with upper and lower milk ducts and a washing device manufactured by OJSC "Bratslav". The scheme of the experimental stand is presented in Figure 1.

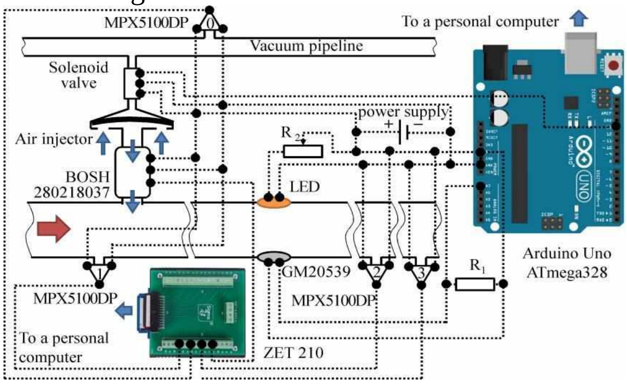


Fig. 1. Scheme of the experimental stand for researching the modes of operation of the air injector of the milking system of the milking system

The stand includes: 1 – milk delivery system; 2 – vacuum system; 3 – photo sensor for determining the contamination of the milk line; 4 – tank with washing solution; 5 – air injector; 6 – washing machine; 7 – electromagnetic valve; 8 – DMVP air mass flow sensor; 9 – MPX5100DP vacuum pressure sensor; 10 – ZET 210 A/D/DAC module; 11 – Arduino Uno ATmega328 control board; 12 – personal computer.

The general appearance of the experimental stand is presented in Figure 2.

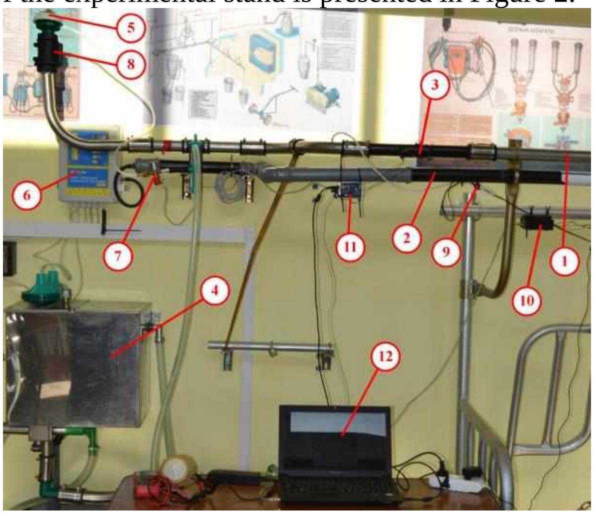


Fig. 2. General view of the experimental stand for researching the modes of operation of the air injector and the photosensor of the system for washing the milk pipes of the milking plant

Factors of experimental research are working vacuum pressure p_w, the duration of the air injector injection stroke t_{inj}, air injector pause duration t_p and volumetric air flows through the air injector Q_V. Limits and intervals of research factors are presented in table. 1.

Table 1

Limits and intervals of factors of experimental studies

Level	Working vacuum pressurep_w, kPa (x_1)	The duration of the air injector injection stroke t_{inj}, s (x_2)	Duration pauses air injector t_p, s (x_3)	Volume flow of air through the air injector Q_V, l/min (x_4)
Upper (+1)	75	9	9	100
Average (0)	60	5	5	200
Lower (–1)	45	1	1	300
Interval	15	4	4	100

Working vacuum pressure p_w installed on a laboratory milking plant using a vacuum regulator and controlled by a MPX5100DP vacuum pressure sensor. The equation of the calibration characteristic of the MPX5100DP vacuum pressure sensor is as follows [5]

$$p = \frac{1}{9}\left(\frac{U_p}{5} - 0{,}04\right), \quad (1)$$

where U_p – voltage from the vacuum pressure sensor MPX5100DP, V. The vacuum pressure measurement error within the studied range is ± 0,1 kPa.

Duration of injection strokes t_{inj} and pauses t_p of the air injector is set using an electromagnetic valve, which is connected to the Arduino Uno ATmega 328 control board. The error of the injection and pause cycles is ± 1 m/s.

Volume flow of air through the air injector Q_V is installed by covering the holes on the air injector and is controlled by the air mass flow sensor DMVP BOSH 280218037. Air mass flow recalculation Q_M to voluminous ones Q_V is carried out according to the following formula:

$$Q_V = \frac{1000}{60}\frac{Q_M}{(101{,}325 - p_w)\mu_a} R_a T_a, \quad (2)$$

where R_a – universal gas table, R_a = 8,314 J/(mol•K); T_a – air temperature, К; μ_a – molar mass of air, μ_a = 28,96 g/mol; Q_V – volumetric air flow, l/min.; Q_M – air mass flow rate, kg/s [5]:

$$Q_M = 0{,}0022U_M + 0{,}0022U_M - 0{,}0044, \quad (3)$$

where U_M – voltage from the air mass flow sensor BOSH 280218037, V.

Before each experiment, the photosensor was removed from the laboratory milking unit, washed, wiped and immersed in a container with milk, where it remained for 20 minutes.

Next, the research factors were set at the required level and the washing machine was started in continuous washing mode for 30 minutes.

In the process of experimental studies, the dynamics of the vacuum pressure on each of the connected sensors was determined (p_0, p_1, p_2, p_3) and the dynamics of resistance change on the photosensor R_f.

The degree of cleanliness is a qualitative criterion for evaluating studies of the operating modes of the system for washing the milk pipes of a milking unit with an air injector θ_{milk}, which is defined as a change in the average value of the thickness of the milk layer h_{milk} on the pipe wall:

$$\theta_{milk} = 100\frac{h''_{milk} - h'_{milk}}{h'_{milk}}, \quad (4)$$

where h'_{milk} – the initial value is the thickness of the milk layer on the pipe wall, m; h''_{milk} – the final value is the thickness of the milk layer on the pipe wall, m.

According to previous laboratory studies [6], the thickness of the milk layer on the pipe wall was determined taking into account the resistance value on the photosensor according to the formula:

$$h_{milk} = \frac{1}{k_{\lambda milk}}\ln\left(\frac{R_f}{R_0}\right), \quad (5)$$

where R_f – the current value of the resistance on the photosensor, Ohm; R_f – the initial value of the resistance on the photosensor, Ohm; $k_{\lambda milk}$ – the indicator of light absorption by milk, which was determined as a result of laboratory studies [6], m $^{-1}$.

It was also necessary to set the value of the time interval Δt_e during which stabilization of the current value of the resistance on the photosensor occurs. The specified time interval Δt_e characterizes the minimum allowable time for washing the milk pipe of the milking installation.

The criterion that limits the operating parameters of the system for washing the milk pipes of the milking unit with an air injector is the value of the pressure change during the injection stroke and the pause of the air injector (speed of pressure change) $\frac{\Delta p}{\Delta t}$, which is calculated by the formula:

$$\frac{\Delta p}{\Delta t} = \frac{p_{max} - p_{min}}{t_{inj} + t_p}. \tag{6}$$

In addition to the quality criterion mentioned above, the gradient of vacuum pressure change, which is calculated according to the formula, is important:

$$\frac{\Delta p}{\Delta L} = \frac{p_3 - p_1}{2l_p}, \tag{7}$$

where l_p – distance between sensors, m.

The greater the rate of change of pressure in the milk pipe of the milking plant, the greater the probability of uncontrolled water hammer, which will destroy not only the layer of milk and milk deposits on the surface of the wall of the milk pipe, but also the milk pipe itself.

Therefore, rational operation modes of the milking system for milking pipes with an air injector can be achieved under the condition of minimizing the value of the thickness of the milk layer on the wall of the milking pipe, the minimum permissible washing time and the speed of pressure change.

Experimental studies were conducted according to the Hartley–Kono (Na-Ko4) plan for four factors at three levels with a total of 18 experiments [6]. Next, using the Wolfram Mathematica software package, a second-order regression model was determined for each of the proposed criteria.

Study of a photo sensor to determine the contamination of the milk pipeline (hereinafter the photo sensor), the diagram of which is presented in Figure 3. The equipment consisted of a personal computer to which a photo sensor based on an Arduino Uno ATmega328 device is directly connected, which controls a 1 W 100 Lm LED through an adjustable resistor 5 kOhm. The analog input of the Arduino Uno ATmega328 is connected to a known 10kΩ, 0.1% resistor that connects to ground (GND) and a GM20539 photoresistor that connects to 5V. The photoresistor is attached to the bottom of the glass tube, which is placed at an angle β to the horizon, and an LED is installed opposite it. The angle of inclination of the glass tube was controlled by a digital protractor. The glass tube is completely isolated from external light by a black opaque material.

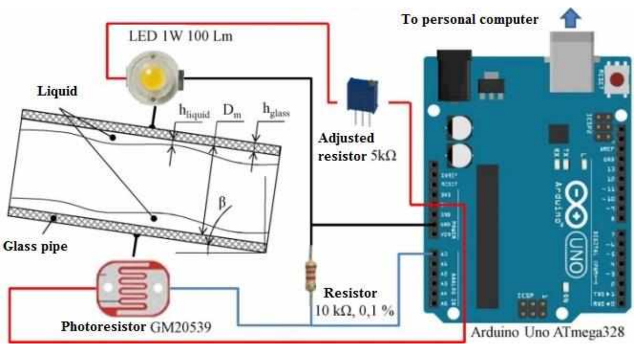


Fig. 3. Scheme of a photosensor for determining the dependence of the intensity of light absorbed by milk on the thickness of its layer

The equipment works as follows. The glass tube is filled with a medium (air, milk, washing solution). Next, the LED is turned on, the light from which passes through the walls of the glass tube and the medium and falls on the photoresistor. At the same time, the resistance of the photoresistor changes and is determined using the Arduino Uno ATmega328 device. The received data are transferred to a personal computer every 2 seconds.

Before beginning the description of the research process, let's establish some dependencies.

Consider how a horizontal glass tube is filled with a liquid of a given volume. According to [7], the volume of liquid is:

$$V = L\left(R_m{}^2 \operatorname{Arccos}\left(1 - \frac{h}{R_m}\right) - (R_m - h)\sqrt{2R_m h - h^2} \right), \quad (8)$$

where L – length of glass tube, L = 0,2 m; R_m – the inner radius of the glass tube, R_m= 0,025 m; h – is the thickness of the liquid layer in the glass tube , m.

By solving equation (1) in the Mathematica software package with respect to h, we get the corresponding dependence, which is presented in Figure 4, b.

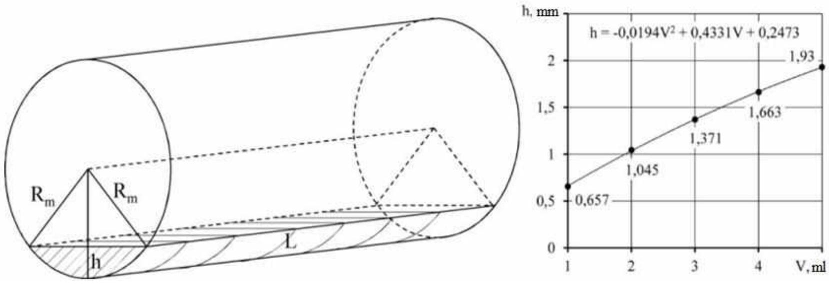


Fig. 4. Scheme of filling a horizontal pipe with a liquid of a given volume (a) and the dependence of the thickness of the liquid layer on its volume (b)

It is known that the dependence of the attenuation of light intensity during its propagation in absorbing media is subject to the Bouguer-Lambert-Behr law [7]. In our case, there are three of them: glass, air and liquid (milk or washing solution). Accordingly, we have

$$I(h) = I_0 \exp(-k_\lambda h), \quad (9)$$

where I(h) – the intensity of light that has passed through a layer of medium thickness h; I_0 – intensity of light at the entrance to the substance; k_λ – indicator of light absorption by the environment [8].

In the case of light passing through a glass tube that is filled with air, the intensity of the light I_1 can be written as:

$$I_1 = I_0 \exp(-2k_{\lambda glass} h_{glass} - k_{\lambda air} D_m). \quad (10)$$

If there is adhesion of milk on the walls, then the light intensity I_2 will be presented as:

$$I_2 = I_0 \exp(-2k_{\lambda glass} h_{glass} - k_{\lambda air}(D_m - h_{milk}) - k_{\lambda milk} h_{milk}), \text{ or}$$
$$I_2 = I_1 \exp(k_{\lambda air} h_{milk} - k_{\lambda milk} h_{milk}). \quad (11)$$

Taking the indicator of light absorption by air $k_{\lambda air} = 10^{-3} \to 0$, we will get

$$I_2 = I_1 \exp(-k_{\lambda milk} h_{milk}). \quad (12)$$

Since the photoresistor changes its resistance R inversely proportionally depending on the intensity of incident light I, we rewrite equation (5) in the form:

$$R_2 = R_1 \exp(k_{\lambda milk} h_{milk}), \text{ or } h_{milk} = \frac{1}{k_{\lambda milk}} \ln\left(\frac{R_2}{R_1}\right). \quad (13)$$

The research process was carried out in two stages.

The first stage begins with the installation of the glass tube horizontally using a digital protractor. Next, with the help of an adjustable resistor on the photo sensor and a personal computer, we achieve such an intensity of light, which spreads from the LED, that the photo resistor has one of the resistance values of 10 kΩ, 15 kΩ, 20 kΩ, 25 kΩ, 30 kΩ and 35 kΩ. This resistance corresponds to the light intensity I1 for the case of light passing through a glass tube that is filled with air. Next, the glass tube is filled with a certain volume of milk: 1 ml, 2 ml, 3 ml, 4 ml, 5 ml. For uniform spreading along the entire length of the tube, exposure is 15 minutes. After that, using a personal computer and a photo sensor, the value of the resistance of the photoresistor, on which the light that was partially absorbed by the milk fell, is measured. As a result, it is necessary to establish the dependence of the thickness of the milk layer on the resistance of the photoresistor.

The second stage begins with the installation of the glass tube using a digital protractor at angles of 2.5 °, 5 °, 7.5 °, 10 °. Next, with the help of an adjustable resistor on the photosensor and a personal computer, we achieve such an intensity of light, which spreads from the LED, that the resistance of the photoresistor is 10 kΩ. This resistance corresponds to the light intensity I1 for the case of light passing through a glass tube that is filled with air. Next, the highest edge of the glass tube is filled with 5 ml of milk. After that, the process of measuring the resistance of the photoresistor and recording the obtained data is started. As a result, it is necessary to establish the dynamics of the resistance of the photoresistor and the corresponding value of the thickness of the layer of milk in the process of its flow down the glass pipe.

3. The purpose of the article

To carry out experimental studies of the operation modes of the air injector of the milking system of milking pipes and to determine its rational values. Develop equipment for automatic detection of contamination of the milk duct line during the technological operation of washing milk duct systems

4. Results of the researches

As a result of research, the dynamics of the vacuum pressure on each of the connected sensors was obtained for each experiment (p_0, p_1, p_2, p_3). We will give an explanation regarding the processes observed on the corresponding graphs (Figure 5). During the opening of the air injector (that is, by connecting it to atmospheric pressure), a sharp drop in the vacuum pressure occurs almost to 0 kPa, which causes a negative water hammer. Due to the constant operation of the vacuum pump and the presence of the receiver, the value of the vacuum pressure is close to the working one p_0 with some damping oscillations. Next, the air injector closes (abruptly disappears due to the combination with atmospheric pressure), which causes a sharp increase in the vacuum pressure (almost twice) and, accordingly, a positive water hammer. Due to the constant operation of the vacuum pump and the presence of the receiver, the value of the vacuum pressure is equalized to the working p_0 according to the decaying sine function.

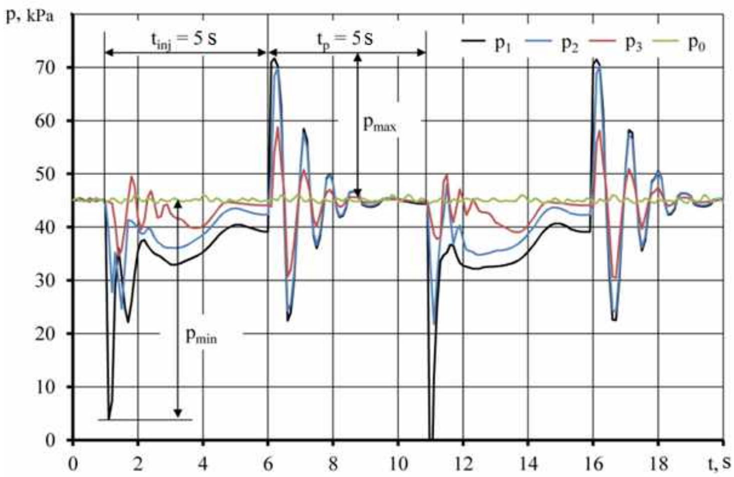


Fig. 5. Dynamics of vacuum pressure on connected sensors (p_0, p_1, p_2, p_3)

The dynamics of the resistance change on the photosensor Rf has the character that is presented in Figure 4. Analyzing the indicated figure, it can be seen that the decrease in resistance on the photosensor R_f from the initial value to the stabilized value R_{fe} characterizes an effective flushing process that is ongoing t_e–t_s. After stabilization of the resistance value on the photosensor, the washing process is not effective.

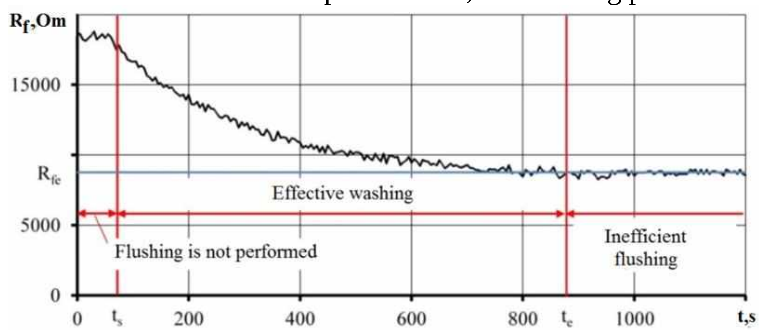


Fig. 6. Dynamics of resistance change on the photosensor R_f

According to the research plan, we will consider the obtained data for each criterion separately.

As a result of experimental studies and further processing of the obtained data in the Wolfram Mathematica software package, the dependence of the change in the degree of purity was obtained θ_{milk} from research factors in coded form:

$$\theta_{milk} = 76{,}7653 - 6{,}70752\,x_1 - 3{,}49731\,x_1^2 - 1{,}88824\,x_2 - 0{,}23882\,x_1 x_2 - 1{,}28554\,x_2^2 - 3{,}84884\,x_3 + 0{,}340515\,x_1 x_3 + 2{,}07749\,x_2 x_3 - 6{,}23266\,x_3^2 + 11{,}2418\,x_4 - 0{,}107728\,x_1 x_4 + 0{,}0858108\,x_2 x_4 + 0{,}592603\,x_3 x_4 + 1{,}10483\,x_4^2. \quad (14)$$

Statistical processing of equation (14) is presented in Table 2.

As a result of the analysis of Table 2, the corresponding reduction of insignificant coefficients according to the Student's criterion $t_{0,05}(36) = 2{,}02$ and decoding equation (14), we finally have the dependence of the change in the value of the degree of purity θ_{milk} from research factors

$$\theta_{milk} = 29{,}5872 + 1{,}42395\,p_w - 0{,}0155436\,p_w^2 + 0{,}0640533\,Q_V - 0{,}0000718187\,p_w Q_V + 0{,}000110483\,Q_V^2 - 0{,}121902\,t_{inj} - 0{,}00398034\,p_w t_{inj} + 0{,}000214527\,Q_V t_{inj} - 0{,}080346\,t_{inj}^2 + 1{,}64717\,t_p + 0{,}00567526\,p_w t_p + 0{,}00148151\,Q_V t_p + 0{,}129843\,t_{inj} t_p - 0{,}389542\,t_p^2. \quad (15)$$

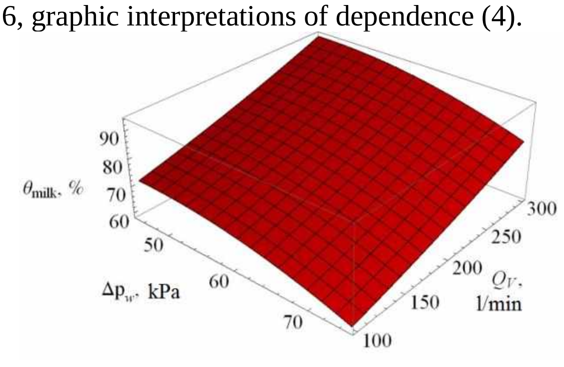
According to the calculated Fisher test for Eq (15) $F = 1{,}96 > F_{0,05}(8;36) = 2{,}21$. This shows that there are no significant statistical differences between the calculated according to equation (15) and the experimental data, and the null hypothesis about the equality of the samples of the calculated and experimental data is confirmed, that is, the mathematical model (15) is adequate.

Table 2

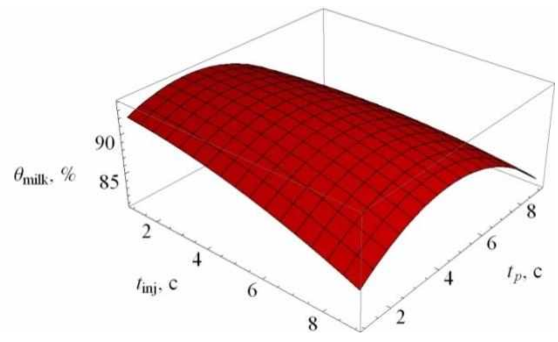
Statistical treatment of the equation (16)

Regression coefficient	The value of the regression coefficient	Standard error	t-statistic	P-Value
a_{00}	76,7653	0,478921	160,288	$5{,}35434\cdot10^{-7}$
a_{10}	–6,70752	0,405545	–16,5395	0,000481078
a_{20}	–1,88824	0,288735	–6,53971	0,00726768
a_{30}	–3,84884	0,226625	–16,9833	0,000444643
a_{40}	11,2418	0,227416	49,4327	0,0000182301
a_{12}	–0,23882	0,380664	–0,627378	0,574915
a_{13}	0,340515	0,252094	1,35075	0,269627
a_{14}	–0,107728	0,242665	–0,443938	0,687156
a_{23}	2,07749	0,290825	7,14344	0,00564843
a_{24}	0,0858108	0,24597	0,348867	0,750238
a_{34}	0,592603	0,260907	2,27132	0,107794
a_{11}	–3,49731	0,592834	–5,8993	0,00972467
a_{22}	–1,28554	0,459157	–2,79977	0,0678657
a_{33}	–6,23266	0,622532	–10,0118	0,00212106
a_{44}	1,10483	0,380872	2,9008	0,0624616
a_{00}	76,7653	0,478921	160,288	$5{,}35434\cdot10^{-7}$

The maximum value of the degree of cleanliness of the milk duct θ_{milk}= 94,0% is achieved at p_w = 45,5 kPa, t_{inj}= 1,1 s, t_p = 3,2 s, Q_V = 300 l/min. Fixing in turn the research factors at the indicated level, constructed in fig. 6, graphic interpretations of dependence (4).



a



b

Fig. 6. Dependence of the value of the degree of cleanliness of the milk duct θ_{milk} from research factors: a – working vacuum pressure p_w and volumetric air flows through the air injector Q_V; b – is the duration of the air injector injection cycle t_{inj} and air injector pause duration t_p

The analysis of Figure 5 and dependence (11) makes it possible to assert the variability of injector operating modes. So with an increase in the working vacuum pressure p_w and volume flow of air through the air injector Q_V the degree of cleanliness of the milk duct θ_{milk} increases This observation is quite logical, since the interaction of the shock wave, which occurs as a result of pulsations of vacuum pressure, with the layer of milk on the walls of the milk duct increases. For the duration of the injection strokes t_{inj} and pauses t_p of the air injector, there is an optimum at which the degree of cleanliness of the milk duct is observed θ_{milk} is the maximum. At the lowest stroke values, the propagation speed of the shock wave is high, which leads to a decrease in the speed of its interaction with the layer of milk on the walls of the milk duct. At the highest stroke values, the magnitude of the shock wave is not large, which leads to a less destructive effect on the layer of milk, which is placed on the walls of the milk duct.

As a result of experimental studies and further processing of the obtained data in the Wolfram Mathematica software package, the dependence of the pressure change during the injection stroke time and the pause of the air injector (speed of pressure change) on the research factors was obtained in coded form

$$\frac{\Delta p}{\Delta t} = 34{,}494 + 3{,}65198\, x_1 – 2{,}6524\, x_1^2 – 12{,}1905\, x_2 – 3{,}02649\, x_1 x_2 + 12{,}738\, x_2^2 – 8{,}07975\, x_3 – 1{,}6205\, x_1 x_3 + 12{,}9931\, x_2 x_3 – 0{,}878323\, x_3^2 + 14{,}5057\, x_4 – 0{,}170093\, x_1 x_4 + 0{,}144456\, x_2 x_4 + 0{,}286004\, x_3 x_4 + 0{,}370808\, x_4^2. \quad (16)$$

Statistical processing of equation (16) is presented in Table 3.

Table 3

Statistical treatment of the equation (16)

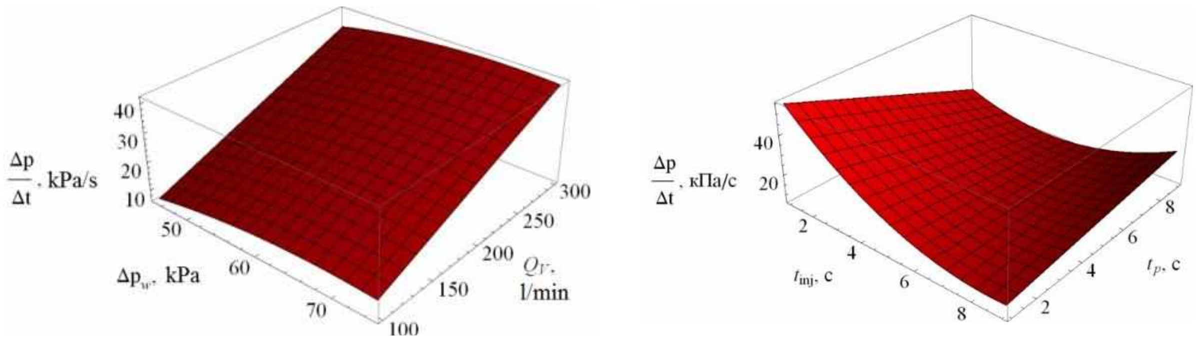
Regression coefficient	The value of the regression coefficient	Standard error	t-statistic	P-Value
a_{00}	34,494	0,335887	102,695	$2{,}0355\cdot10^{-6}$
a_{10}	3,65198	0,284426	12,8398	0,0010195
a_{20}	–12,1905	0,202502	–60,1996	0,0000100985
a_{30}	–8,07975	0,158942	–50,8347	0,0000167643
a_{40}	14,5057	0,159496	90,9474	$2{,}93029\cdot10^{-6}$
a_{12}	–3,02649	0,266975	–11,3362	0,00147243
a_{13}	–1,6205	0,176804	–9,16549	0,00274598
a_{14}	–0,170093	0,170191	–0,999427	0,391239
a_{23}	12,9931	0,203968	63,7017	$8{,}52378\cdot10^{-6}$
a_{24}	0,144456	0,172509	0,837382	0,463839
a_{34}	0,286004	0,182985	1,56299	0,215996
a_{11}	–2,6524	0,415779	–6,37935	0,00779828
a_{22}	12,738	0,322026	39,5559	0,0000355498
a_{33}	–0,878323	0,436608	–2,0117	0,137757
a_{44}	0,370808	0,267121	1,38816	0,259212
a_{00}	34,494	0,335887	102,695	$2{,}0355\cdot10^{-6}$

As a result of the analysis of Table 3, the corresponding reduction of insignificant coefficients according to the Student's criterion $t_{0,05}(36) = 2{,}02$ and decoding equation (16), we finally have the dependence of the rate of pressure change on research factors

$$\frac{\Delta p}{\Delta t} = – 9{,}25598 + 2{,}04533\, p_w – 0{,}0117884\, p_w^2 + 0{,}145057\, Q_V – 12{,}0428\, t_{inj} – 0{,}0504414\, p_w t_{inj} + 0{,}796128\, t_{inj}^2 – 4{,}45978\, t_p – 0{,}0270083\, p_w t_p + 0{,}812068\, t_{inj} t_p. \quad (17)$$

According to the calculated Fisher test for Eq (17) $F = 1{,}08 > F_{0,05}(8;36) = 2{,}21$. This shows that there are no significant statistical differences between the calculated according to equation (17) and the experimental data, and the null hypothesis about the equality of the samples of the calculated and experimental data is confirmed, that is, the mathematical model (17) is adequate.

The minimum value of the pressure change rate $\frac{\Delta p}{\Delta t} = 6{,}93$ kPa/s is reached at $p_w = 45$ kPa/, $t_{inj}=4{,}39$ s, $t_p = 1{,}0$ c, $Q_V= 100$ l/mi. Fixing in turn the research factors at the indicated level, constructed in fig. 7, graphic interpretations of dependence (17).



a ***b***

Fig. 7. Dependence of the value of the pressure change rate $\frac{\Delta p}{\Delta t}$ from research factors: a – working vacuum pressure p_w and volumetric air flows through the air injector Q_V; b – is the duration of the air injector injection cycle t_{inj} and air injector pause duration t_p

With an increase in the working vacuum pressure p_w, volume flow of air through the air injector Q_V and air injector pause duration t_p the rate of change of pressure increases. And vice versa with an increase in the duration of the injection stroke of the air injector t_{inj} the rate of pressure change decreases.

Due to the fact that the rational parameters differ, it is necessary to solve a compromise problem, which boils down to minimizing the value of the rate of change of pressure at the highest value of the degree of cleanliness of the milk duct:

$$\begin{cases} \theta_{milk}(p_w, t_{inj}, t_p, Q_V) \to \max, \\ \frac{\Delta p}{\Delta t}(p_w, t_{inj}, t_p, Q_V) \to \min. \end{cases} \quad (18)$$

By solving the system of equations (18) in the Wolfram Mathematica software package, we obtain the rational parameters of the injector operating modes:

$$p_w = 45,0 \text{ kPa}, \; t_{inj} = 5{,}2 \text{ s}, \; t_p = 4{,}2 \text{ s}, \; Q_V = 295 \text{ l/min.},$$

$$\theta_{milk} = 92{,}1\%, \; \frac{\Delta p}{\Delta t} = 42{,}4 \text{ kPa/s}. \quad (19)$$

As a result of the first stage, data were obtained, which are summarized in Table 4.

Table 4

Summary data of the first stage of research

V, Jr	h, mm	R_1, Ohm	R_2, O Ohm	$\ln(R_2/R_1)$	V, Jr	h, mm	R_1, Ohm	R_2, Ohm	$\ln(R_2/R_1)$
1	0,657	10000	11547	0,1438	1	0,657	25000	28839	0,1428
2	1,045		13774	0,3202	2	1,045		34619	0,3255
3	1,371		15976	0,4685	3	1,371		40747	0,4885
4	1,663		18543	0,6175	4	1,663		45789	0,6052
5	1,93		21476	0,7644	5	1,93		54175	0,7734
1	0,657	15000	18257	0,1965	1	0,657	30000	34664	0,1445
2	1,045		21468	0,3585	2	1,045		41116	0,3152
3	1,371		25235	0,5202	3	1,371		47057	0,4502
4	1,663		28824	0,6532	4	1,663		56244	0,6285
5	1,93		33585	0,8060	5	1,93		63893	0,7560
1	0,657	20000	21916	0,0915	1	0,657	35000	36429	0,1942
2	1,045		26503	0,2815	2	1,045		42851	0,3565
3	1,371		30293	0,4152	3	1,371		50301	0,5168
4	1,663		35834	0,5832	4	1,663		57591	0,6522
5	1,93		41172	0,7220	5	1,93		67013	0,8037

The graphical interpretation of Table 1 is presented in Figure 8. The correlation coefficient of the obtained data is 0.9896. Taking this into account, it is possible to assert the correctness of the choice of the method of estimating the thickness of the layer of milk remaining on the wall of the milk line. At the same time, the light absorption index of the selected milk is 494.1 m^{-1}.

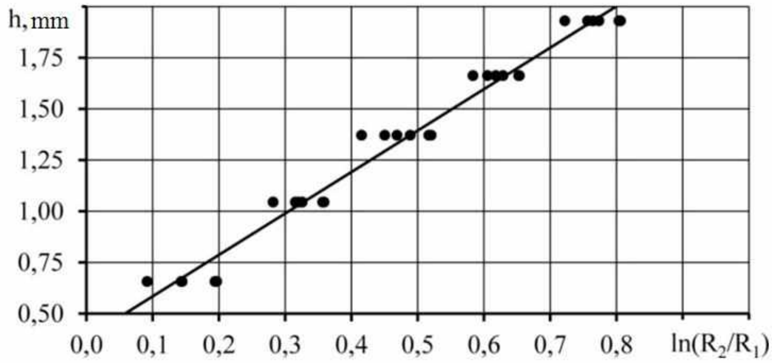


Fig. 8. Dependence of the thickness of the milk layer on the resistance of the photoresistor

As a result of the second stage, the data shown in Figure 9 were obtained, which shows the dynamics of the logarithm of the resistance ratio of the photoresistor, which is proportional to the value of the thickness of the milk layer, during its flow down the glass pipe.

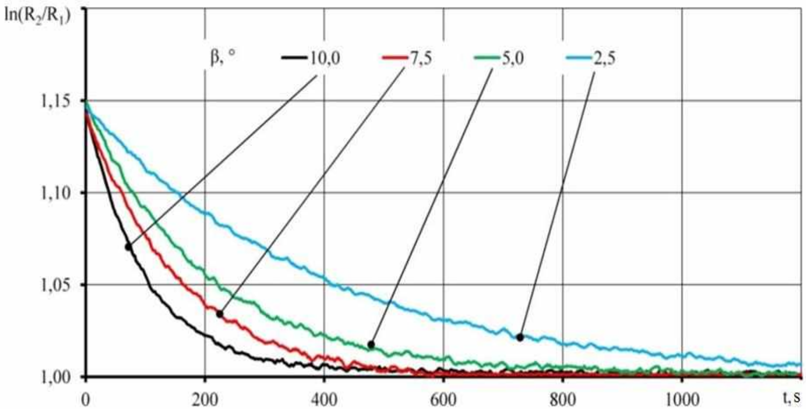


Fig. 9. Dynamics of the logarithm of the resistance ratio of the photoresistor, which is proportional to the value of the thickness of the layer of milk, during its flow down the glass pipe

5. Conclusions

As a result of experimental studies of the modes of operation of the air injector of the system of washing the milk pipes of the milking plant, the dependence of the speed of pressure change was established $\Delta P/\Delta t$ and changes in the degree of cleanliness of the milk duct θ_{milk} from the working vacuum pressure p_w, volume flow of air through the air injector Q_V, duration of the air injector injection stroke t_{inj} and the duration of the air injector pause t_p.

Solving the compromise problem, which is reduced to the minimization of the value of the rate of change of pressure at the highest value of the degree of purity of the milk pipe, the appropriate rational parameters of the injector operating modes are obtained: p_w = 45,0 kPa, t_{inj}=5,2 s, t_p = 4,2 s, Q_V= 295 l/min., θ_{milk} = 92,1%, $\Delta P/\Delta t$ = 42,4 kPa/s.

As a result of the research, the feasibility of using the developed equipment for automatic determination of the contamination of the milk supply line during the technological operation of washing milk supply systems has been established. The dependence of the thickness of the milk layer moving in the glass tube on the resistance of the photoresistor, which sinks the light that is partially absorbed by the milk layer, is also established.

References

1. Coj, J.A., Mamedova, R.A. (2005). The influence of parameters milk pipeline of milking installation on modes of motion an gas-liquid to mixtures. *Problemy intensyfikacji produkcji zwierzecej z uwzgledmemem ochrony srodowiska i standardow UE*, 355–359. [in English].

2. Shevchenko, I.A., Aliiev, E.B. (2013). *Naukovo-metodychni rekomendatsiyi z bahatokryterial'noho vyrobnychoho kontrolyu doyil'nykh ustanovok [Scientific and methodical recommendations on multicriteria production control of milking parlors]*. Edited by Doctor of Technical Sciences, Professor, Corresponding Member of NAAS of Ukraine, I.A. Shevchenko. Zaporizhzhia: Accent Invest-trade. ISBN 978-966-2602-41-VIII. [in Ukrainian].
3. Aliiev, E.B. (2011). Optymizatsiia tekhnikotekhnolohichnykh parametriv vakuumnoi systemy doilnoi ustanovky [Optimization of technical and technological parameters of the milking machine vacuum system]. *Zbirnyk naukovykh prats Tavriiskoho derzhavnoho ahrotekhnolohichnoho universytetu, 12 (1),* 138–147. DOI: 10.31388/2078- 0877-19-3-14-21 [in Ukrainian].
4. Aliiev, E.B. (2012). Doslidzhennia metrolohichnykh kharakterystyk komplektu ustatkuvannia kontroliu vakuummetrychnykh parametriv molochno-doilnoho obladnannia [Investigation of metrological characteristics of a set of equipment for monitoring the vacuum parameters of milking and milking equipment]. *Ahrarna nauka ta praktyka na suchasnomu etapi rozvytku: dosvid, problemy ta shliakhy yikh vyrishennia, Mizhnarodna naukovo-praktychna konferentsiia.* Lviv: Lvivska ahrarna fundatsiia, 13–15. [in Ukrainian].
5. Babyn, I.A. (2018). Doslidzhennya metrolohichnykh kharakterystyk prystroyu dlya vymiryuvannya vakuummetrychnykh parametriv liniyi promyvky doyil′noyi ustanovky. [Study of the metrological characteristics of the device for measuring the vacuum parameters of the washing line of the milking plant]. *Engineering, Energy, Transport AIC, 3 (102),* 5–10. [in Ukrainian].
6. Kyselov, O.V., Komarova, I.B., Milko, D.O., Bakardzhyiev, R.O. (2017). Statystychna obrobka i oformlennia rezultativ eksperymentalnykh doslidzhen (iz dosvidu napysannia dysertatsiinykh robit): Navchal′nyy posibnyk [Statistical processing and design of experimental research results (from the experience of writing dissertation papers): Study guide]. *Instytut mekhanizatsiyi tvarynnytstva NAAN. Elektronnyy analoh drukovanoho vydannya (elektronna knyha),* 1181. Zaporizhzhia: STATUS. [in Ukrainian].
7. Gunko, I., Babyn, I., Aliiev, E., Yaropud, V., Hrytsun, A. (2021). Research into operating modes of the air injector of the milking parlor flushing system. *UPB Scientific Bulletin, Series D: Mechanical Engineering. 83(2),* 297–309. URL: http://dspace.dsau.dp.ua/jspui/handle/123456789/5420 [in English].
8. Aliiev, E.B. (2012) Pidvyshchennya efektyvnosti ekspluatatsiyi vakuumnoyi systemy molochnodoyilnoho obladnannya: dys. ... kand. tekhn. nauk: 05.05.11. [Improving the efficiency of the operation of the vacuum system of milkmilking equipment: thesis...candidate technical Sciences: 05.05.11.], 177. Zaporizhzhia. [in Ukrainian].
9. Fenenko, A.I. (2008). *Mekhanizatsiya doyinnya koriv. [Mechanization of milking cows].* Teoriya i praktyka: Monohrafiya. Kyiv. [in Ukrainian].
10. Paliy, A.P. (2018). *Obgruntuvannya, rozrobka ta efektyvnist' zastosuvannya innovatsiynykh tekhnolohiy i tekhnichnykh rishen' u molochnomu skotarstvi [Justification, development and effectiveness of the application of innovative technologies and technical solutions in dairy farming].* Avtoreferat dysertatsiyi na zdobuttya naukovoho stupenya doktora sil′s′kohospodars′kykh nauk. Mykolayiv. [in Ukrainian].
11. Babyn, I.A. (2021). Rezul′taty doslidzhen′ hidrodynamichnoyi systemy promyvannya doyil′nykh ustanovok [Results of research on the hydrodynamic system of washing milking plants]. *Engineering, Energy, Transport AIC, 4(115),* 45–55. DOI: 10.37128/2520-6168-2021-4-5 [in Ukrainian].
12. Babyn, I.A. (2021). Doslidzhennya impul′snoyi vibratsiyi periodychno pratsyuyuchoho inzhektora systemy promyvannya doyil′nykh ustanovok [Study of impulse vibration of periodically working injector of milking system washing system]. *Vibratsiyi v tekhnitsi ta tekhnolohiyakh, 4(103),* 47–60. DOI: 0.37128/2306-8744-2021-4-6 [in Ukrainian].
13. Hrytsun, A.V., Babyn, I.A. (2020). Teoretychni obgruntuvannya deyakykh konstruktyvno-tekhnolohichnykh parametriv doyil′noho aparatu z kerovanym rezhymom doyinnya [Theoretical substantiation of some structural and technological parameters of a milking machine with a controlled milking mode]. *Engineering, Energy, Transport AIC, 2(109),* 16–27. DOI: 10.37128/2520-6168-2020-2-2 [in Ukrainian].
14. Pryshliak, V.M, Babyn, I.A., Hunko, I.V. (2020). Modelyuvannya rezhymiv roboty systemy promyvannya molokoprovodiv molochno-doyil′noho obladnannya iz povitryanym inzhektorom [Modeling of the operation modes of the milk duct flushing system of milking equipment with an air injector]. *Visnyk ahrarnoyi nauky Prychornomoria, 1 (105),* 102–109. DOI: 10.31521/2313-092X/2020-1(105)-13. [in Ukrainian].

15. Hunko, I.V., Babyn, I.A. (2020). Fizyko-matematychna model′ roboty hidroinzhektora systemy promyvannya doyil′nykh ustanovok [Physico-mathematical model of operation of the hydraulic injector of the washing system of milking installations]. *Vibratsiyi v tekhnitsi ta tekhnolohiyakh, 2(97),* 111–118. DOI: 10.37128/2306-8744-2020-1-12 [in Ukrainian].
16. Gunko, I., Babyn, I., Pryshliak, V. (2020). Eksperymental′ni doslidzhennya rezhymiv roboty povitryanoho inzhektora systemy promyvannya molokoprovodiv doyil′noyi ustanovky [Experimental studies of the air injector system operating modes of the milk washing system]. *Naukovi horyzonty, 3(88),* 44–53. doi: 10.33249/2663-2144-2020-88-3-44-53 [in Ukrainian].

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ СТЕНДУ АВТОМАТИЗОВАНОЇ СИСТЕМИ ПРОМИВАННЯ ДОЇЛЬНОЇ УСТАНОВКИ З ПОВІТРЯНИМИ ІНЖЕКТОРАМИ ТА ФОТОДАТЧИКОМ ДЛЯ ВИЗНАЧЕННЯ РІВНЯ ЗАБРУДНЕННЯ

Один з ключових показників якості молока, яке використовується для подальшої переробки – це рівень бактеріального забруднення. Цей параметр безпосередньо залежить від санітарно-гігієнічного обслуговування доїльного обладнання, швидкості охолодження молока та впливу інших зовнішніх факторів.

Під час доїння молоко проходить через різні елементи системи, такі як доїльні апарати, молокопроводи, молокозбірники, індивідуальні та групові лічильники тощо. Ці елементи можуть стати джерелами бактеріального забруднення. Щоб покращити якість молока, рекомендується підвищити ефективність промивання доїльних установок, що включає подовження тривалості промивки. Однак це призводить до збільшення експлуатаційних витрат (води, мийних засобів, електроенергії тощо) і, відповідно, собівартості молочної продукції.

З часом на внутрішніх поверхнях молокопроводів утворюються відкладення лужної та кислотної природи, які різняться за складом, властивостями та міцністю зчеплення з поверхнею. Дане забруднення призводить до бактеріального забруднення молока, що знижує його якість і термін зберігання.

Для покращення якості промивки було запропоновано використовувати інжектор, який періодично подає повітря в молокопровідну лінію. Це створює значні коливання вакуумметричного тиску, що, в свою чергу, викликає контрольовані гідроудари. Керування цим процесом повинно здійснюватися автоматизованими системами молочно-доїльного обладнання.

Якість роботи системи промивки важко оцінити і контролювати без спеціальних датчиків і пристроїв для вимірювання забрудненості молокопроводу. Мета дослідження полягає в проведенні експериментальних випробувань режимів роботи повітряного інжектора системи промивання молокопроводів і визначенні його оптимальних параметрів. Також передбачається розробка обладнання для автоматичного визначення забрудненості молокопроводу під час промивки.

В експериментальних дослідженнях були виявлені залежності між швидкістю зміни тиску та рівнем чистоти молокопроводу, а також між робочим вакуумметричним тиском, об'ємними витратами повітря через інжектор, тривалістю впускання повітря та тривалістю паузи. Для досягнення компромісу, який полягає у мінімізації швидкості зміни тиску при максимальному рівні чистоти молокопроводу, були визначені оптимальні параметри режимів роботи інжектора. Показано доцільність використання розробленого обладнання для автоматичного контролю забрудненості молокопроводу під час промивання. Також встановлено залежність товщини шару молока, що рухається в скляній трубі, від опору фоторезистора, на який впливає світло, що частково поглинається молоком.

Ключові слова: *доїльна установка, система промивки, інжектор, параметри, експериментальні дослідження, ступень частоти, миючий розчин, фотодатчик, забрудненість, молокопровідна лінія.*

Ф. 19. Рис. 9. Табл. 4. Літ. 16.

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