26. Povyshenie resursa tekhnicheskih sistem putem ispol'zovaniya elektricheskih i magnitnyh poley: monografiya / Aleksandrov E. E., Kravets I. A., Lysikov E. N. et. al. Kharkiv: NTU «KhPI», 2006. 544 p.
27. Lysikov E. N., Voronin S. V., Konovalov P. E. Ispol'zovanie effekta elektroobrabotki zhidkih smazochnyh sred v tyazhelyh rezhimah raboty podshipnikov: zb. nauk. pr. // Ukrainska derzhavna akademiya zaliznychnoho transportu. 2010. Issue 115. P. 122–127.
28. Instruktsiya TsT-0060 z vykorystannia mastylnykh materyaliv na tiahovomu rukhomomu skladi zaliznyts Ukrainy. Kyiv: Derzh. admin. zalizn. transportu Ukrainy, 2003. 54 p.
29. Sidenko V. M., Grushko I. M. Osnovy nauchnyh issledovaniy. Kharkiv: Vysshaya shkola, 1977. 287 p.
30. Braun E. D., Evdokimov Yu. A., Chichinadze A. V. Modelirovanie treniya iznashivaniya v mashinah. Moscow: Mashinostroenie, 1982. 191 p.

Досліджено взаємозв'язок між конструкційно-технологічними параметрами колектора та режимами транспортування молока до молокопроводу. Запропонована конструкція двосекційного колектора. Отримана математична модель, яка пов'язує інтенсивність молоковіддачі з технологічними параметрами розробленого колектора, залежно від режимів доїння. Встановлено раціональні співвідношення між конструкційним об'ємом молочної камери колектора та діаметром молочного шланга

Ключові слова: градієнт тиску, дросельний отвір, швидкість доїння, подача повітря, якість молока

Исследована взаимосвязь между конструкционно-технологическими параметрами коллектора и режимами транспортировки молока к молокопроводу. Предложена конструкция двухсекционного коллектора. Получена математическая модель, которая связывает интенсивность молокоотдачи с технологическими параметрами разработанного коллектора, в зависимости от режимов доения. Предложены рациональные соотношения между конструкционным объемом молочной камеры коллектора и диаметром молочного шланга

Ключевые слова: градиент давления, дроссельное отверстие, скорость доения, подача воздуха, качество молока

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ESTABLISHING RATIONAL STRUCTURAL-TECHNOLOGICAL PARAMETERS OF THE MILKING MACHINE COLLECTOR

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1. Introduction

The milking machine is designed to perform a very important biotechnological function in the system of machine milking of cows – removal of the created milk from the udder. In this case, main operations are executed by the milking cups. Direct contact with the body of an animal requires taking into consideration anatomic structure of quarters of the udder. The implementation of cycles of milk removal and pressing is the only assignment of milking cups in a general system of machine-animal-human-environment. It is important in the process of machine milking of cows to completely remove milk formed in the udder [1, 2]. It is known that the level and stability of vacuum pressure are essential to the completeness of milking and the preservation of animal health [2–6]. It was established [7, 8] that systematic fluctuations in pressure cause the loss of cow productivity by 9.2 %. Insufficient level of vacuum pressure leads to a decrease in milk production by 14 %; there is the effect of «ballooning» nipple rubber, which causes coming down of the milking cups [8–10]. At a high vacuum, there is the increased danger for cows of the disease of mastitis.

The overflow of the collector with milk during the tact of sucking and an incomplete emptying of the milk chamber changes the level of pressure under the nipple of a cow. Thus, the collector of a milking machine is essential to maintaining the desired level and stable vacuum pressure. In turn, the complete discharge of milk from the collector of the milking chamber depends on the rational structural-technological parameters of the transportation system. Unstable conditions of transportation cause the frothing of milk, dispersing the fat globules and, as a consequence, deterioration of milk quality [8, 13]. This is especially relevant for the milking plants with the upper milk pipeline. The problem is of significant scale because more than 80 % of all commercial herd of cows are milked using milking machines of the «milk pipeline» type [13].

Thus, it is important to design a collector of the milking machine that would positively influence the completeness of implementation of the productive potential of animals, the preservation of quality of obtained milk, as well as improve efficiency of machine milking in general.

2. Literature review and problem statement

Contemporary milking machines have permanent air supply (8–10 l/min) to the collector's milk chamber [1, 13]. It is believed that such a solution ensures reliable transportation of milk to the upper milk pipeline. Continuous intake of air over 5–6 minutes of the duration of machine milking causes a change in pressure in the under-nipple space [2, 3, 10]. Since milk release fluctuates within a significant range (from 0.2 to 6–8 l/min), the mode of milk transportation through a milk hose changes as well [13, 14]. A different ratio between milk and air is formed in the milk hose, and a different pressure drop, accordingly. At the insufficient pressure drop a portion of milk fails to rise to the milk pipeline during one pulse. Returning the milk to the collector results in increasing pressure losses for the transportation of next portion [4]. Pulsating motion and significant fluctuations in pressure occur, which reduces the efficiency of the transporting link [6, 13]. In addition, fluctuation of pressure negatively affects the health of cows [5, 9].

It is proposed to eliminate the fluctuation of pressure caused by the irregular milk release through the enlargement of volume of the collector's milk chamber. The design of the collector with the enlarged volume of milk chamber and portion-wise air supply through a valve [15] partially solves the problem of pulsation. However, significant complexity in the design of collector requires further examination of a given solution. Instead, scientists [13] recommended limiting the volume of milk chamber at the level of 150–250 ml, and a diameter of the milk hose should not exceed 14 mm. Continuous air supply to the collector must be combined with a pair-wise milking regime. Such a mode of operation of the milking machine reduces the instantaneous amount of milk in the collector's milk chamber while a continuous flow of air must create a transporting pressure difference.

A variety of commercially available collector designs testifies to the constant search for its rational structural-technological scheme. Some structural solutions considerably complicate design of the collector, which makes it more expensive. In this case, the influence of air and its amount on the quality indicators of milk is not taken into consideration. Thus, in the milk hose, under the influence of a strong stream of air, there occurs the dispersing of milk. Breaking down milk globules into tiny structures leads to a reduction in the bactericidal phase of milk [11, 13]. In addition, milk is churned when it is transported by excessive air flow. Fat globules exfoliate and remain on the walls of the milk pipeline system. It was established that 0.32 % of milk fat is lost as a result of such processes [11, 13]; this negatively affects the technological properties of milk.

Still unresolved is the task on establishing a rational correlation between structural parameters of the collector's milk chamber and resource-saving modes of milk transportation through a milk hose to the milk pipeline. For this purpose, it is necessary to align air supply to the milk chamber over a tact of compression and the intensity of milk release in order to ensure a transporting difference of pressure.

Thus, the lack of scientifically substantiated structural-technological parameters and operation modes necessitates undertaking research into establishing a rational structural-functional scheme of the milking machine collector.

3. The aim and objectives of the study

The aim of present study is to enhance effectiveness of milking into the upper milk pipeline by improving a structural-technological scheme of the milking machine collector.

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

– to establish the impact of parameters of the collector's milk chamber on the operational modes of a milking machine;

– to find a rational structural-technological scheme of the milking machine collector;

– to substantiate rational parameters for the system of transporting milk from the collector to the upper milk pipeline.

4. Materials and methods for studying the collector of a milking machine

Structural parameters of milking machines and their operation modes must exert a minimum influence on a change in the quality indicators of obtained milk. It is known that in contemporary milking machines a source of the milk quality deterioration is the air that penetrates the collector's milk chamber from the outside. In addition, continuous intake of air causes fluctuations in the level of vacuum pressure. It is possible to eliminate negative manifestations by changing the collector's structural-technological scheme. We propose an improved design of the collector [16, 17] with a dual milk chamber and the intake of air only during a compression tact (Fig. 1).

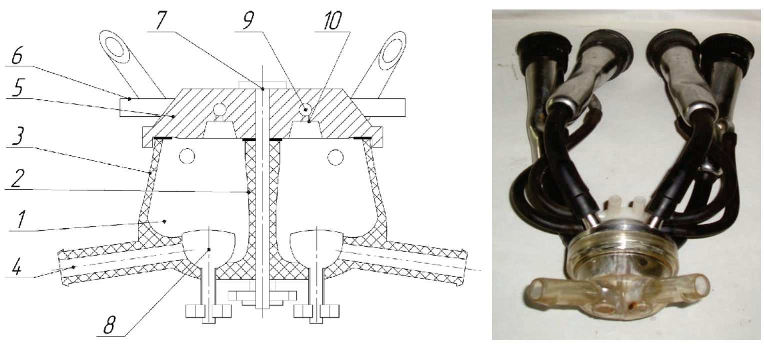

Fig. 1. Designed milk collector of a milking machine: *a* — structural-technological scheme: 1 — milk chamber; 2 — partition; 3 — housing; 4 — milk branch pipe; 5 — cover with an air-separating chamber; 6 — air pipes to the inter-wall spaces of milking cups; 7 — coupling mechanism; 8 — cut-off valve; 9 — air pipe to pulsator; 10 — throttle opening; *b* — experimental sample

Each milk collecting chamber of the collector is connected to the milk pipeline via a separate milk pipeline hose (Fig. 1). During the tact of compression, air arrives to the milk collecting chambers through valve openings. Such a solution will improve the mode of milk transportation, stabilize pressure in a milk collecting chamber during the tact of sucking, and will ensure effective «blowing» during the tact of compression.

In order to solve the set tasks, we shall apply methods of theoretical research. Theoretical research is based on the application of the theory of mathematical modeling using basic provisions of the integral and differential calculus, hydro gas dynamics, heat engineering and vacuum technology (methods of classical sciences). Processing of the research results was performed applying provisions of the theory of probability and mathematical statistics, using the software packages Statistica 10 and Microsoft Excel 2010.

5. Results of the research into parameters of the transporting link milk collector-milk pipeline

To improve the transporting capability of the designed collector, a milk collecting chamber during the tact of compression must receive air at atmospheric pressure. The duration of filling with air depends on the structural volume of the collector's milk chamber, diameter of the throttle opening, and the magnitudes of pressure at the beginning of the tact on both sides of the opening. Thus, over a certain period dt, the collector's milk chamber, through a throttle opening, will receive air of volume V_v with intensity Q_n, which will change the pressure on dp. We shall construct a differential equation of material balance:

$$Q_n p dt = V_v dp, \tag{1}$$

where p is the variable magnitude of pressure over dt, kPa; Q_n is the intensity of air intake through the throttle opening, m^3/s; V_v is the volume of air that changes pressure on dp, m^3.

By dividing the variables, we performed integration under initial conditions ($t=t_0=0$; $p=p_m$) and obtained the solution:

$$p_{mc} = p_m \cdot e^{\frac{Q_n}{V_v} t_{ct}}, \tag{2}$$

where p_{mc} is the pressure in the collector's milk chamber during the tact of compression, kPa; p_m is the pressure in the collector's milk chamber during milk release, kPa; t_{ct} is the duration of the compression tact, s.

The volume of air V_v depends on the degree of filling the milk chamber during milk release. Since milk release is not constant in intensity, the pressure in the collector's milk chamber accepts different values. In order to establish the level of pressure p_m, we shall employ the Boyle-Mariotte law [18–20], we obtain:

$$p_m = \frac{p_s V_m}{V_p} = \frac{p_s V_m}{V_m - \frac{1}{2}\left(Q_m - Q_m e^{-t_s}\right) t_{st}}, \tag{3}$$

where p_s is the pressure in the collector's milk chamber at the beginning of the tact of sucking, kPa; V_m is the structural volume of the collector's milk chamber, m^3; V_p is the volume taken by air in the collector's milk chamber at pressure p_m, m^3; t_s is the time coordinate of the tact of sucking (it accepts values from 0 to t_{st}), s; t_{st} is the duration of sucking tact, s; Q_m is the intensity of milk release, m^3/s.

Coefficient 1/2 in equation (3) is determined by the design of the proposed two-section collector's milk chamber, each part of which receives milk only from two milking cups at pairwise milking. The negative value of the time coordinate of a sucking tact indicates a constant uninterrupted flow of milk through the outlet branch pipe. Thus, pressure p_m has a variable magnitude during sucking tact (Fig. 2) and depends on the degree of filling the collector's milk chamber with milk.

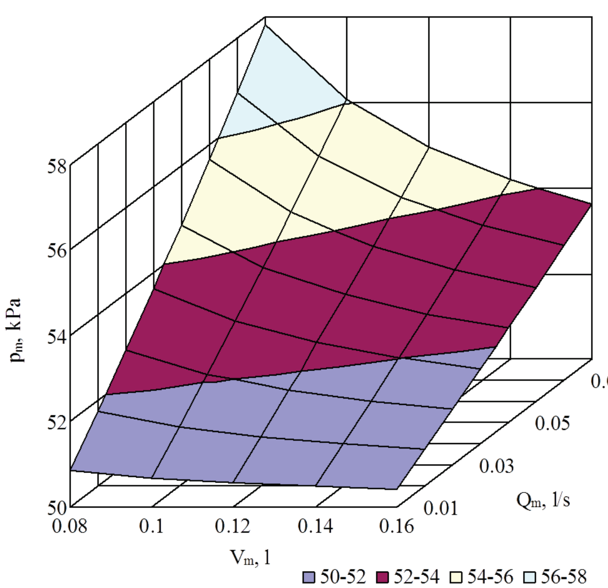

Fig. 2. Dependence of the magnitude of pressure p_m on the intensity of milk release (Q_m) and structural volume of the collector's milk collecting chamber (V_m), under condition of initial pressure p_s=50 kPa and duration of the tact of sucking t_{st}=0.6 s

An increase in the volume of a milk collecting chamber of the collector (Fig. 2) results in the decrease in pressure at the end of a sucking tact (p_m) regardless of the intensity of milk release (Q_m). However, at a fixed volume of the milk collecting chamber of the collector, pressure p_m increases when the intensity of milk release grows.

The character of change in pressure can be explained by a change in the volume taken by milk in the collector's milk chamber. Thus, at the intensity of milk release from 0.005 to 0.04 l/s, the volume free of milk grows by 50–54 % with an increase in the volume of the collector's milk chamber from 0.08 to 0.16 l. Regardless of the volume of the collector's milk collecting chamber, the volume taken by milk increases to 87.5 % at an increase in the intensity of milk release from 0.005 to 0.04 l/s.

In order to ensure guaranteed milk transportation through the milk hose to the main milk pipeline, the following condition must be satisfied:

$$p_{mc} \geq p_{mh} + \Delta p_h, \tag{4}$$

where p_{mh} is the pressure in a milk pipeline, kPa; Δp_h are the pressure losses in a milk hose when transporting a portion of milk, kPa.

In order to determine the loss of pressure Δp_h, the following equation was analytically derived:

$$\Delta p_h = \rho_m \frac{2Q_m}{\pi d_h^2}\cos\alpha\left(gt_{st} + l_h\right) + $$
$$+ 0.2028 Q_m^2 \rho_m \left(\frac{\lambda_h l_h}{d_h^5} + \frac{\xi_s + \xi_p + \xi_n}{d_h^4}\right), \tag{5}$$

where ρ_m is the density of milk, kg/m^3; α is the inclination angle of the milk hose, degrees; d_h is the diameter of the milk hose, m; g is the free fall acceleration, m/s^2; l_h is the length of the milk hose, m; λ_h is the hydraulic friction coefficient; ξ_s, ξ_p, ξ_n is the coefficient of local resistance at contraction, expansion, change in direction and in the turn of the flow of milk in the milk hose, respectively.

Pressure in the collector's milk chamber rises from the starting magnitude to level p_{mc} due to the supply of air through the throttle opening. The intensity of air supply (Q_n) must provide for the required transporting pressure difference, which is:

$$Q_n = \frac{p_s\left(V_m^2 - V_m\right)}{\left(p_{mh} + \Delta p_h\right)\left(V_m t_{ct} - \frac{1}{2} Q_m t_{st} t_{ct} - t_{ct}\right)}, \tag{6}$$

where t_{ct} is the duration of compression tact, s.

By applying formula (6), it is possible to determine the required actual air supply to the collector's milk collecting chamber in order to satisfy condition (4). Structural parameters of the transporting link and the mode of operation of the milking machine influence the intensity of air supply (Fig. 3).

At an increase in the diameter of the milk hose (Fig. 3) the intensity of air supply (Q_n) depends significantly on the intensity of milk release. Thus, within the range of diameter of the milk hose from 10 to 16 mm the intensity of air supply for Q_m = 0.12 l/s grows by 22.4 %, while for Q_m = 0.02 l/s only by 2 %. This indicates the importance of the right choice of a rational diameter for a milk hose in order to ensure a guaranteed condition for the transportation of a portion of milk to the main milk pipeline. Under condition of the maximal value for the intensity of milk release (Q_m = 0.12 l/s) and the smallest diameter of the milk hose (d_h = 10 mm), one observes the minimally required supply of air (Q_n = 0.18 l/s).

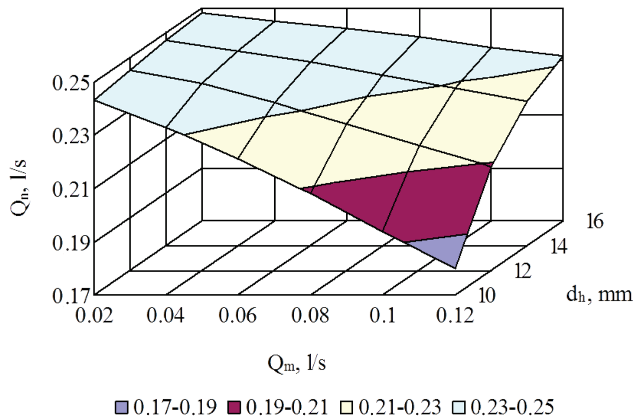

Fig. 3. Dependence of the intensity of air supply (Q_n) on diameter of the milk hose (d_h) and intensity of milk release (Q_m) at a structural volume of the section of a milk collecting chamber V_m = 0.10 l

An important structural parameter of the designed collector is the diameter of the throttle opening. Depending on the intensity of air intake and a pressure difference between the separating chamber and the milk chamber of the collector, with respect to equations (3) and (6), a diameter of the throttle opening is derived from formula:

$$d = 1.129 \cdot \left(\frac{Q_n p_r}{p_{mh} + \Delta p_h}\right)^{0.5} \cdot \left(\frac{\rho_r}{2\left(p_r - p_m\right)}\right)^{0.25}, \tag{7}$$

where ρ_r is the air density at pressure p_r, kg/m^3; p_r is the air pressure in the separating chamber of the collector during compression tact, kPa.

The larger volume of the section of the collector's milk chamber (V_m) is matched with a larger diameter of the throttle opening (d), regardless of the intensity of milk release (Fig. 4).

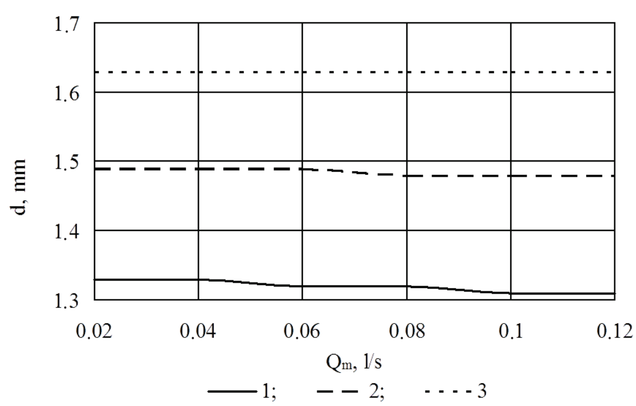

Fig. 4. Dependence of diameter of the throttle opening (d) on the intensity of milk release (Q_m) and diameter of the milk hose (d_h) in combination with a fixed structural volume of the section of a milk collecting chamber (V_m): 1 — V_m = 0.08 l, d_h = 12 mm; 2 — V_m = 0,1 l, d_h = 14 mm; 3 — V_m = 0.12 l, d_h = 16 mm

According to Fig. 4, at a certain combination of diameter of the milk hose (d_h) and the structural volume of the section of a collector's milk chamber (V_m), a diameter of the throttle opening is almost unchanged. Therefore, the diameter of the throttle opening (d) may have a constant magnitude regardless of the intensity of milk release. However, an increasing diameter of the milk hose (d_h) requires a larger diameter of the throttle opening (d). This is observed in the examined range of volumes of sections of the collector's milk chambers (V_m) regardless of the intensity of milk release (Q_m).

6. Discussion of results of studying structural parameters and modes of functioning of the collector of a milking machine

The proposed structural solutions of the designed collector make it possible to eliminate the reasons that accompany the milk flow pulsation, dispersing the fat globules and, accordingly, the deterioration of its technological properties.

We propose a mode of operation under which milk collecting sections of the collector receives the air only during the tact of compression. The intensity of air supply is controlled by the volume of section of the milk chamber, by a diameter of the throttle opening, and depends on the magnitude of pressures at the start of the tact on both sides of the opening. In a combination with the pairwise mode of operation of the milking machine, it improves the efficiency of transporting a portion of milk to the upper milk pipeline of the milking plant.

Maintaining quality indicators of milk is achieved by aligning the intensity of air supply to the section of the milk chamber to the intensity of milk release. Under such condition, a portion of milk remains intact and it is not destroyed while transported to the main milk pipeline. This follows from the accepted mode of air supply to the collector's milk collecting chamber – during the tact of compression. That is why each portion of the received milk will be kept in the milk hose, between two air plugs. The losses of pressure caused by the displacement of air flow through a milk hose will not exert any significant impact on the overall losses of head. This is explained by the much lower density of air in comparison with the density of milk.

Important for ensuring the efficient transportation of milk to the milk pipeline is the volume of milk chamber and a diameter of the milk hose. Depending on the structural volume of the milk chamber and the intensity of milk release, the desired intensity of air supply is assigned. Thus, the larger volume of the milk chamber is matched with a higher supply of air at constant intensity of milk release. An increase in the intensity of milk release leads to a decrease in the supply of air at the expense of reduction in the volume of the collector's milk chamber free from milk. The diameter of a milk hose determines the high-speed modes of transporting milk to the milk pipeline, due to the impact on the intensity of air supply.

Therefore, choosing the right rational diameter of the flexible milk pipeline would improve the mode of milk transportation, especially when milking cows with high productivity.The volume of section of the collector's milk collecting chamber should be aligned with the diameter of a throttle opening. This conclusion is due to a change in the driving pressure difference between the separating chamber and the milk chamber of the collector depending on the mode of milking.

Application of the obtained mathematical dependences would make it possible to establish a rational combination of the structural volume of section of the collector's milk chamber, the diameter of a milk hose and the diameter of a throttle opening. The applied aspect of employing the results of scientific research is the possibility to improve design of collector of the milking machine, which would ensure the preservation of milk quality while transporting it to the upper milk pipeline of the milking plant.

Further research should focus on the substantiation of theoretical calculations by carrying out experimental study. The emphasis should be given to the ratio between milk and air in a general flow of milk-air mixture in the milk hose.

Results of present work confirm the possibility of constructing a structural-functional scheme of collector with rational design-technological parameters, adapted to the modes of milking.

7. Conclusions

1. We established that the variation of structural volume of the collector's milk chamber makes it possible to ensure a safe level and the required stability of pressure in the under-nipple space of the milking cups. It was found that the highest increase in pressure is matched with a smaller volume of the collector's milk chamber, regardless of the intensity of milk release. In this case, an additional increase in pressure improves the mode of transportation of the milk-air mixture to the upper milk pipeline of the milking plant.

2. We have designed a two-section collector of the milking machine that makes it possible to eliminate the negative impact on the quality of the received milk. This is achieved by enabling the desired mode of milk transportation through a milk hose. The distinctive structural-technological feature is the air supply to the milk chamber's section only during the tact of compression. In order to preserve the quality of milk, the air comes through a throttle opening from the separating chamber of the collector. Such a solution stabilizes pressure in the milk collecting chamber during the tact of sucking and ensures effective «blowing» during the tact of compression. This reduces the negative effect of pressure on the nipple of an animal by lowering its level.

3. We established in the course of present research the required intensity of air supply to the section of the collector's milk chamber depending on the diameter of a milk hose. Thus, while increasing the diameter of a milk hose from 10 to 16 mm, it is necessary to increase the intensity of air supply by 2 % to 22.4 % within a milk release intensity of 0.02 l/s to 0.12 l/s. A mathematical model was constructed that connects the diameter of a throttle opening to the intensity of milk release, the intensity of air supply, the diameter of a milk hose, structural volume of section of the milk collecting chamber, and pressure losses in the milk hose. It was determined that at a diameter of the milk hose of 16 mm and a volume of section of the milk chamber of 0.12 l, it will suffice to have a diameter of the throttle opening of 1.63 mm. In this case, the intensity of milk release will not exert any significant impact on the efficiency of transporting a portion of milk.

References

1. Bluemel, F. E., E. Savary, P., E. Schick M. Effects of an extended c-phase on vacuum conditions in the milking cluster // Biosystems Engineering. 2016. Vol. 148. P. 68–75. doi: 10.1016/j.biosystemseng.2016.04.004
2. Kudlai I. M., Lutsenko M. M. Perspektyvni tekhnolohiyi vyrobnytstva moloka // Visnyk Sumskoho natsionalnoho ahrarnoho universytetu. 2010. Issue 7. P. 64–68.
3. Besier J., Bruckmaier R. M. Vacuum levels and milk-flow-dependent vacuum drops affect machine milking performance and teat condition in dairy cows // Journal of Dairy Science. 2016. Vol. 99, Issue 4. P. 3096–3102. doi: 10.3168/jds.2015-10340
4. Effects of quarter individual and conventional milking systems on teat condition / Rose-Meierhöfer S., Müller A. B., Mittmann L., Demba S., Entorf A.-C., Hoffmann G. et. al. // Preventive Veterinary Medicine. 2014. Vol. 113, Issue 4. P. 556–564. doi: 10.1016/j.prevetmed.2014.01.006
5. Hovinen M., Pyörälä S. Invited review: Udder health of dairy cows in automatic milking // Journal of Dairy Science. 2011. Vol. 94, Issue 2. P. 547–562. doi: 10.3168/jds.2010-3556
6. Effect of pulsation rest phase duration on teat end congestion / Upton J., Penry J. F., Rasmussen M. D., Thompson P. D., Reinemann D. J. // Journal of Dairy Science. 2016. Vol. 99, Issue 5. P. 3958–3965. doi: 10.3168/jds.2015-10466
7. Mein G. A. The Role of the Milking Machine in Mastitis Control // Veterinary Clinics of North America: Food Animal Practice. 2012. Vol. 28, Issue 2. P. 307–320. doi: 10.1016/j.cvfa.2012.03.004
8. Kartashov L. P. Mashinnoe doenie korov. Moscow: Kolos, 1982. 301 p.
9. Besier J., Lind O., Bruckmaier R. M. Dynamics of teat-end vacuum during machine milking: types, causes and impacts on teat condition and udder health – a literature review // Journal of Applied Animal Research. 2015. Vol. 44, Issue 1. P. 263–272. doi: 10.1080/09712119.2015.1031780
10. Ströbel U., Rose-Meierhöfer R., Brunsch R. Design of a vacuum control system with frequent teat-end vacuum adaption for milking machines // Proceedings International Conference of Agricultural Engineering. Zurich, 2014. P. 1–6.
11. Paliy A. P. Vplyv molokoprovidnykh system doilnykh ustanovok na spozhyvchi pokaznyky moloka // Tvarynnytstvo Ukrainy. 2016. Issue 9. P. 20–22.
12. Smoliar V. Riven zakhvoriuvanosti koriv na mastyt za vykorystannia riznykh typiv doilnykh ustanovok // Tekhnika i tekhnolohii APK. 2014. Issue 1. P. 17–20.
13. Fenenko A. I. Mekhanizatsiya doinnia koriv. Teoriya i praktyka: monohrafiya. Kyiv, 2008. 198 p.
14. Pavlenko S. I., Aliyev E. B., Lynnyk Yu. O. Metodyka eksperymentalnykh doslidzhen protsesu peremishchennia molokopovitrianoi sumishi v doilnomu aparati // Naukovyi visnyk Tavriyskoho derzhavnoho ahrotekhnolohichnoho universytetu. 2015. Vol. 2, Issue 5. P. 167–172.
15. Fenenko A. I. Tekhniko-tekhnolohichni aspekty udoskonalennia biotekhnichnoi lanky «mashyna-tvaryna» protsesu vyrobnytstva moloka // Mekhanizatsiia i elektryfikatsiya silskoho hospodarstva. 2007. Issue 91. P. 65–77.
16. Achkevych V. I., Tkach V. V. Do obgruntuvannia parametriv dvokhkamernoho kolektora doilnoho aparata z poparnym pulsatorom // Mekhanizatsiya i elektryfikatsiya silskoho hospodarstva. 2014. Vol. 1, Issue 99. P. 506–509.
17. Kolektor doilnoho aparata: Pat. No. 66812 UA. MPK A01J 7/00 / Fenenko A. I., Achkevych V. I., Driho V. O., Mykhailenko P. M.; zaiavnyk i patentovlasnyk Fenenko A. I., Achkevych V. I., Driho V. O., Mykhailenko P. M. No. 201104208; declareted: 07.04.2011; published: 25.01.2012, Bul. No. 2.
18. Idel'chik I. E. Spravochnik po gidravlicheskim soprotivleniyam / M. O. Shteynberg (Ed.). 3-e izd., pererab. i dop. Moscow: Mashinostroenie, 1992. 672 p.
19. Loytsyanskiy L. G. Mekhanika zhidkosti i gaza: ucheb. 7-e izd., ispr. Moscow: Drofa, 2003. 840 p.
20. Vakuumnaya tekhnika: spravochnik / Frolov E. S., Minaychev V. E., Aleksandrova A. T. et. al.; E. S. Frolov, V. E. Minaychev (Eds.). Moscow: Mashinostroenie, 1992. 480 p.