Innovative technology for zoo veterinary treatment of sheep in mountain regions

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Abstract. This paper analyzes the technological and organizational features of conducting zoo veterinary treatments of sheep on farms and cooperatives in the mountainous regions of the Kyrgyz Republic. The influence of the spatial fragmentation of farms, the small number of sheep, and the seasonality of production processes on the efficiency of using stationary zoo veterinary treatment units is studied. The limitations of existing stationary processing lines associated with their high metal consumption, low mobility, and insufficient adaptation to the conditions of grazing sheep are identified. The principles of organizing mobile service units performing a range of zoo veterinary operations based on the "equipment to animals" principle directly in areas where sheep congregate are studied. A mathematical description of the functioning of the mobile unit is developed based on the theory of aggregate systems and elements of queueing theory for analyzing the interaction of process units. Probabilistic patterns of the arrival of groups of sheep for processing and parameters for coordinating the performance of the process sections of the unit are established. A structural model of the technological process has been developed, including the steps of shearing, grading, vaccination, anti-scab bathing, and primary wool processing. A design and process flow diagram for a mobile unit with dismountable and portable equipment and an autonomous power supply from a low-pressure microhydroelectric power station has been proposed. Analytical and empirical relationships have been developed for calculating the main design parameters and operational characteristics of the unit. The use of a sorption method for disinfecting spent acaricidal solutions using brown coal from local deposits, ensuring the environmental safety of the technological process, is justified.

1 Introduction

The Kyrgyz Republic is experiencing a growing need to implement innovative technologies aimed at improving the efficiency of agricultural production and accelerating the country's economic development. Approximately 76% of the population lives in rural areas and is

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primarily employed in the agricultural sector. The country's natural and climatic conditions, as well as historically established farming traditions, facilitate the development of livestock farming, which accounts for 45-47% of gross agricultural output. In recent years, there has been a steady increase in the number of livestock and poultry (excluding pigs) at a rate of 4-5% annually, while the breed composition of the animals has improved. For example, the number of sheep and goats in the country has reached 7.1 million [1].

Sheep farming is particularly important for the economy of mountainous regions, accounting for up to 90% of rural income. The effective development of this industry is determined not only by improving breed composition and providing adequate nutrition, but also by timely implementation of a comprehensive range of veterinary procedures, including shearing, preventative bathing, vaccination, treatment, and animal assessment. In today's agricultural production environment, mechanization and automation of labor-intensive technological processes play a crucial role, ensuring increased productivity, improved working conditions and safety for personnel, and improved quality of agricultural products through the timely execution of production operations. Global experience shows that mechanization of livestock processes not only improves production efficiency but also reduces the impact of harmful factors on humans and improves the environmental health of the industry, as farm animals, their products, and waste can all be sources of various diseases.

However, in the current conditions of farms and cooperatives in the Kyrgyz Republic, a number of problems exist that hinder the effective implementation of veterinary treatments for sheep. The small number of sheep on individual farms, the significant distance between farms, and the low production volumes make the use of stationary veterinary treatment stations economically impractical. Furthermore, previously functioning stationary shearing stations and dousing units, which provided a high level of mechanization of technological processes (up to 95-98%), have now been dismantled in most cases. Furthermore, new technological solutions and technical equipment adapted to modern farm conditions have not been sufficiently developed.

As a result, the main types of veterinary treatments for sheep - shearing, preventative dousing, vaccination, animal treatment, and grading - are often performed haphazardly and are accompanied by violations of environmental requirements, safety regulations, and electrical safety. A significant problem remains the high labor intensity of operations related to catching and transporting animals to the processing site. Each technological operation requires catching and hauling sheep manually, requiring physical energy expenditure of 19,360 kJ, significantly exceeding the permissible level of 420 kJ [2]. Nationally, this translates into approximately 28.4–35.5 million unmechanized operations annually involving catching and transporting sheep and goats.

The aim of this study is to improve the efficiency of sheep farming by developing an innovative technology for the veterinary treatment of sheep based on a mobile unit, taking into account modern economic practices in the Kyrgyz Republic.

To achieve this goal, the following objectives were addressed:

– Analysis and generalization of existing methods and technical means for the veterinary treatment of sheep;

– Development of an innovative technology for the veterinary treatment of sheep based on a mobile unit with dismountable and portable process equipment and an autonomous power supply from a micro-hydroelectric power station.

Brief analysis of the literature: An analysis of the scientific and technical literature shows that a wide range of technical means has been developed to mechanize technological processes in sheep farming: trolleys, conveyors, conveyors, grippers, and various lifting devices designed to transport animals to processing sites. Process lines for the continuous processing of sheep using conveyor systems have been developed [3], in which shearing and preventive treatment against scabies are performed in a single flow. In these systems, the developers succeeded in combining the operations of feeding sheep to the shearers and to the bathing tank using a single technological device. Furthermore, CAD models of sheep shearing machines using ADAMS software [4] were developed, as well as mobile sheep veterinary treatment stations with improved shearing equipment performance [5, 6]. A well-developed system of sheep shearing and primary wool processing technologies has been developed internationally, with particular attention paid to the quality of animal processing and worker safety [7, 8].

However, most existing technical solutions are characterized by complex designs, stationary nature, and insufficient adaptation to farm conditions [9]. Therefore, the development of mobile technological equipment that enables a range of veterinary treatments for sheep directly at their farms is a pressing issue.

2 Materials and methods

The innovative technology for veterinary treatment of sheep is based on a mobile unit [10] (Figure 1): a - transport position; b - working position (in plan); c - section A-A.

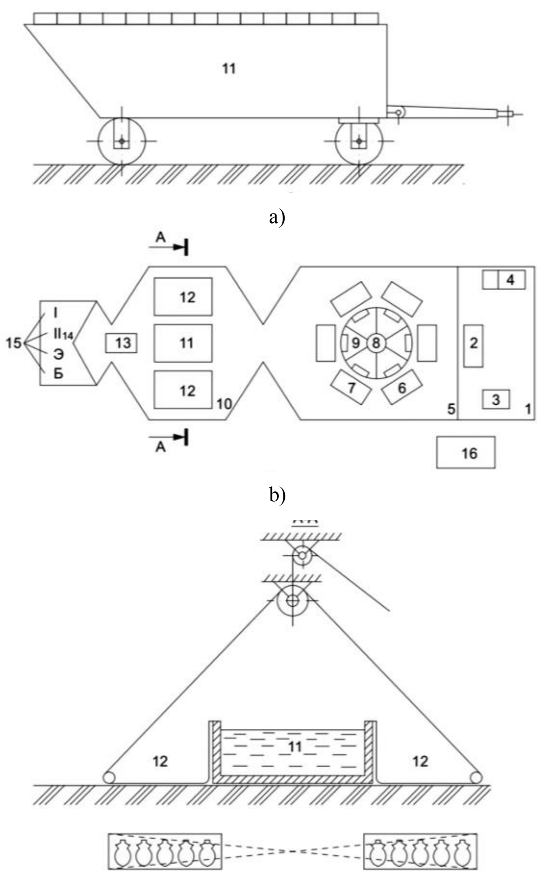

Figure 1. Mobile unit for zooveterinary treatment of sheep: transport position; b - working position (in plan); c - section A-A.

The unit comprises: a primary wool processing section 1, where a classifying table 2, a wool press 3 and a carding device 4 (for coarse and semi-coarse wool) are located; a section 5 for shearing, grading and vaccinating sheep, where racks 6 and shearing machines 7 are evenly distributed around a circular pen 8, the pen being divided into six sectors by beams 9; a section 10 for anti-scab treatment of sheep, where a bathing bath 11, a device for feeding sheep into the bath 12 and a device for removing liquid from the sheep's wool 13 are located; a flock formation section 14 with splits 15 for dividing the sheep into classes. The unit is powered independently by a micro hydroelectric power station (16). Tractors and light-duty vehicles can be used for transport.

The unit operates as follows. Sheep to be processed are driven into pen 8 with the beams 9 raised, and the beam assembly mounted on the side of the pen. When the beams are lowered, individual sectors are formed opposite each rack 6. After shearing, the sheep are vaccinated and graded (for breeding stock) while they remain in a fixed position. The fleece is fed to classifying table 2, then to press 3 (for fine-wool sheep) or to carding unit 4 (for coarse and semi-coarse wool).

Sheared sheep are driven onto device 12 for delivery to bathing tank 11. This device is operated by a lift with a cable-pulley mechanism and an electric drive. In bathing tank 11, the sheep freely swim for up to 1 minute and exit via a ramp to an outlet where a device 13 for removing excess fluid from the sheep's wool is located. As the sheep interact with this device, the bulk of the acaricidal liquid flows back into the tank. Bathed sheep are sorted into classes using splitters 15 (on breeding farms), while on commercial farms, no division into classes is performed.

The technological processes of veterinary treatment of sheep in this installation are described using queueing theory [11].

The mathematical description of the installation's operation is provided by the theory of aggregate systems. In this case, the simulated object is divided into subsystems, while the existing technological connections between them are preserved. Sheep exiting one treatment can be considered as entering another (subsequent) treatment. In this case, the sheep exiting the j treatment and entering the ($j+1$) treatment vary randomly. The number of sheep processed n_0 in the setup depends on their daily t_c and seasonal incoming T_c:

$$n_0 = n_0\left[\varphi(t_c)\right], \varphi(T_c). \tag{1}$$

According to the technological process, sheep n_0 *(t)* are initially placed in a circular pen. Time is measured from a certain initial moment t_0. Each sheep is characterized by a random arrival time t_j and does not leave the unit until it has undergone all processing steps. In this case, the following distribution laws may apply: exponential, normal, uniform, and others. Since sheep arrive at the unit irregularly, no more than one group of sheep arrives in a given time period.

The main objectives of the technology are as follows: interlinking technological processes and operations by their duration; subordinating the time for each processing step in each section to the flow rhythm; ensuring a uniform workload for service personnel and determining their number.

Optimal solutions to these problems have a significant impact on the utilization rate of the technological equipment.

Figure 2 shows a structural model and a flow chart of the technological process for the studied sheep veterinary treatment technology.

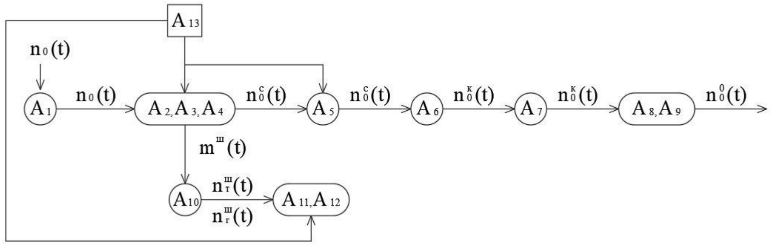

Figure 2. Structural model and diagram of the technological process of veterinary treatment of sheep: A_1 - circular pen; A_2, A_3 and A_4 - device for shearing, grading and vaccination of sheep; A_5 - device for feeding sheep into the dousing tank; A_6 - dousing tank; A_7 - device for removing liquid from sheep wool; A_8 - common pen; A_9 - splits; A_{10} - classification table; A_{11} - wool press; A_{12} - carding device; A_{13} - micro hydroelectric power station.

A group of sheep $n_0(t)$ entering circular pen A_1 during shift t_c is represented by integer random variables n_{oj} with distribution $\{P_{noj}\}$(j=1,2,3,…). This number of sheep $n_0(t)$ is processed in units: A_2 (shearing), A_3 (grading), and A_4 (vaccination). The shorn group of sheep is sent to units A_5 and A_6, where they undergo anti-mange treatment. After bathing $n_o^к(t)$ the sheep are sent to unit A_7 to remove excess fluid from their wool, and are then separated into classes (on breeding farms). The resulting group of sheep $n_o^0(t)$ has undergone all types of veterinary treatment. The shorn wool mass is sorted $m^ш(t)$ in unit A_{10}, then sent to unit A_{11} for pressing as a mass $m_T^ш(t)$ (where $m_T^ш(t)$ is the mass of fine-wool or semi-fine-wool), or sent to unit A_{12} for carding as a mass $m_Г^ш(t)$ (where $m_Г^ш(t)$ is the mass of coarse-wool and semi-coarse-wool). In this scheme, units A_2, A_5, A_{11}, and A_{12} are the consumers of electrical energy.

For example, the following situations may arise between units A_1 and A_2 at time t_j:

1. At time t_j, unit A_2 is ready to interact with unit A1 and enters a standby state. In this situation, the flow of the technological process is not disrupted;
2. At time t_j, unit A_1 is ready to interact with unit A_2, but unit A_2 is not yet ready for interaction. In this situation, the flow of the technological process is disrupted.

Similar situations may arise during interaction between the above-mentioned adjacent units: A_1 and A_2; A_2 and A_5; A_5 and A_6; A_6 and A_7; A_6 and A_8, A_9; A_2 and A_{10}; A_{10} and A_{11}, A_{12}; A_2 and A_3, A_4. To avoid the situation according to point 2, it is necessary to justify the areas of units S_{A1}, S_{A2}, S_{A5}, S_{A8}, and S_{A9} in accordance with the following inequalities: $S_{A1} \leq S_{A2} \leq S_{A5} \leq S_{A8} \leq S_{A9}$, as well as the productivity (throughput) of units $П_{A2}$, $П_{A5}$, $П_{A6}$, and $П_{A7}$ in accordance with the inequalities: $П_{A2} \leq П_{A5} \leq П_{A6} \leq П_{A7}$.

3 Research results

The initial data for determining the most efficient area for the S_{A1} circular pen is based on the results of a survey of sheep numbers on Kyrgyz farms. A survey of 230 farms revealed that the average number of sheep per farm ranges from n_i = 80 to 120 (Figure 3).

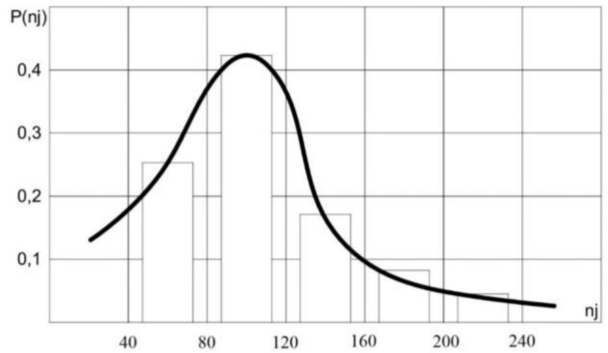

Figure 3. Histogram and probability distribution of sheep count frequency on farms in the Kyrgyz Republic.

The average number of sheep n_i allows us to determine the area of the circular pen S_{A1}:

$$S_{A1} = (1 + k_c) n_i \Delta F, \qquad (2)$$

Where k_c is the coefficient accounting for the freed area of the pen during sheep shearing;

ΔF is the standard area occupied by one sheep (ΔF = 0.53...0.7 m^2/head) [12].

Since the entire flock of sheep in the circular pen is subject to shearing, the k_c coefficient is zero. Then, the average area of the circular pen is: SA1 = 1·100·0.615 = =61m^2. Based on the inequality of the areas of units A_1, A_2, A_5, A_8, and A_9, we have S_{A1} = 61 ≤ S_{A1}=61≤ S_{A2}≤ S_{A5}≤ S_{A8}≤ S_{A9} (m^2).

The experimental parameters for determining sheep shearing productivity are presented in Table 1.

Table 1. Shearing performance of one group of 120 sheep.

Indicators	Empirical distribution equations	Static indicators	
		M_t, min	$\pm\sigma_t$, min
Time to drive sheep into a circular pen, min	$\tau_{A1}=1.018 \cdot e^{-0.0345 \cdot t}$	17.3	6.0
Shearing time for one group of sheep, min	$\tau_{A2}=7.004 \cdot e^{-0.013 \cdot t}$	125.6	12.2
Complete shearing cycle for one group of sheep, min	$T_{cmp}=\tau_{A1}+\tau_{A2}$	142.9	18.2
Shearing capacity, sheep/hour	$\Pi_{A2} = \frac{n_i \cdot 60}{T_{cmp}}$	52	±6

The condition for maintaining the flow of shearing and anti-mange bathing of sheep is $\Pi_{A2} \le \Pi_{A5}$ (where Π_{A5} is the productivity of bathing sheep), and the condition for maintaining the technological process of bathing sheep is:

$$\Pi_{A5}^{подг} \le \Pi_{A5}^{под} \le \Pi_{A5}^{к.в} = \Pi_{A5}, \qquad (3)$$

Where $\Pi_{A5}^{подг}$ is the sheep drive rate to the dousing unit, sheep/hour;

$\Pi_{A5}^{под}$ is the sheep feed rate into the dousing tank, (dousing rate), sheep/hour;

$\Pi_{A5}^{к.в}$ is the dousing tank throughput (throughput), sheep/hour.

The sheep feed rate into the dousing tank $\Pi_{A5}^{под}$ and the tank throughput are determined $\Pi_{A5}^{к.в}$ using well-known formulas:

$$\Pi_{A5}^{под} = \frac{60 \cdot K_з \cdot S_{A5}}{\tau_{A5}^{под} \cdot \Delta F}\eta_к \tag{4}$$

$$\Pi_{A5}^{к.в} = 3600 \cdot \Lambda_1 \cdot \nu_1 = 3600 \cdot \Lambda_2 \cdot \nu_2 = ... = 3600 \cdot \Lambda_n \cdot \nu_n \tag{5}$$

Where $K_з$ is the fill factor of the sheep feeding device;

$\tau_{A5}^{под}$ is the time it takes for the sheep to be uniformly fed into the bath, h;

η_k is the efficiency of the sheep feeding device;

Λ_1, Λ_2, ... Λ_n are the linear densities of sheep in the bath, sheep per meter;

ν_1, ν_2, ... ν_n are the swimming speeds of sheep in specific areas of the bath, m/s.

The data from the timing studies to determine sheep bathing performance are presented in Table 2.

Table 2. Bathing performance of one group of 120 sheep.

Indicators	Empirical distribution equations	Static indicators	
		M_t, min	**$\pm\sigma_t$, min**
Time to drive sheep onto the device platform, min	$\tau_{A5}^{заг} = 1{,}325 \cdot e^{-0{,}0475t}$	17.1	6.0
Time to feed sheep into the bathing tank, min	$\tau_{A5}^{под} = 3{,}07 \cdot e^{-0{,}018 \cdot t}$	51.3	7.0
Dipping time for one group of sheep in the bath, min	$\tau_{A5} = 3.06 \cdot e^{-0.018 \cdot t}$	50.2	7.1
Efficiency of the unit		0.55	
Dipping capacity, sheep/hour	$\Pi_{A5} = (\frac{60 \cdot K_з \cdot S_{A5}}{\tau_{A5}^{под} \cdot \Delta F})\eta_к$	59	±7

It has been established that during bathing, the swimming speed of sheep toward the exit of the bathing tank gradually decreases as they tire. The following inequalities exist: $\nu_1 > \nu_2 > \ldots > \nu_n$ and $\Lambda_1 < \Lambda_2 < \ldots < \Lambda_n$. The relationship $\Lambda = f(\nu)$ is a hyperbola. With an average sheep length of 1 m, the linear density $\Lambda_1 = 1$. With this linear density, sheep tend to crowd together in the tank (especially noticeable at the exit). This leads to injury to the animals, and bathing them is not recommended.

Using a device for removing liquid from sheep's wool, installed at the exit of the bathing tank, removes up to 79 percent of the liquid flowing from the animal's wool during natural settling. The liquid removed per sheep is 2.37-2.93 kg, with a live weight of 40-45 kg.

This sheep veterinary treatment technology involves disinfecting the spent bathing solution using a sorption method. The sorbents used are brown coal mined in the Kyrgyz Republic and a mixture of rubber lids and powdered carbonaceous-siliceous shale in a 1:40 ratio. The spent solution is disinfected using a special device [13, 14].

To determine the feasibility of powering the mobile unit's process equipment, flow data from small rivers in Kyrgyzstan with average flow rates ranging from 0.11 to 12.4 m^3/s was studied. It was found that the average water flow intervals between small rivers obey an exponential distribution law:

$$f(Q_{av}) = 0.6388 * e^{-0.266 * Qav} \tag{6}$$

With a mathematical expectation of 3.112 m^3/s and a standard deviation of 2.46 m^3/s.

A low-pressure micro hydroelectric power plant with an average flow rate of 0.652 m^3/s generates up to 9 kW of electricity, which is sufficient to power the mobile unit's process equipment. Kyrgyzstan's small rivers are distributed relatively evenly across the country.

4 Discussion

As a result of research and development, a technological and structural design for a mobile unit was developed, enabling a comprehensive range of veterinary treatments for sheep at sheep concentration sites. A system of patents for inventions and utility models was used, enabling a new combination, interconnection, and placement of technical equipment. The interaction of technological processes is reflected in the mobile unit's control structure as a multi-level hierarchical system. This technology improves working conditions, reduces human-animal contact, and reduces animal stress, all of which contribute to the health of service personnel and animal productivity.

The mobile unit's design features low metal consumption and is easy to manufacture and assemble. Commonly used vehicles (cars and tractors) can be used for transportation. These factors contribute to reduced costs for sheep veterinary treatment and the unit's competitiveness. The unit can be used on farms with various sheep herd sizes, both in mountainous regions and on flatlands. The unit's capacity ensures consistent animal treatment during seasonal operations, ensuring high-quality results.

5 Conclusion

Based on the results of the study:

1. An innovative technology for sheep veterinary treatment has been developed based on a mobile unit with dismountable and portable process equipment, designed to perform a range of technological operations directly in areas where animals congregate. The unit's design is adapted to the modern operating conditions of farms and cooperatives in the Kyrgyz Republic and provides for an autonomous power supply from a low-pressure microhydroelectric power station.

2. Based on theoretical and experimental studies, the key technological and design parameters of the mobile unit have been determined. The sheep shearing process was found to be efficient at 52±6 sheep/hour, while the anti-scab treatment (bathing) process was found to be efficient at 59±7 sheep/hour. The mass of fluid removed from the wool of one sheep after bathing was 2.37–2.93 kg.

3. The resulting analytical and empirical relationships allowed us to substantiate the key operating parameters of the plant's process units and ensure the coordination of their performance within the unified sheep veterinary treatment process.

4. The proposed technology and the mobile plant's design and process flow diagram can be used on farms and cooperatives with varying sheep herd sizes, including in remote and mountainous regions, thereby reducing the labor intensity of process operations, increasing the effectiveness of veterinary measures, and improving the environmental safety of production.

References

1. National Statistical Committee of the Kyrgyz Republic, *Livestock Farming* (Uchkun, Bishkek, 2023).
2. Zh. Absatov, *Mechanization of Shearing and Primary Wool Processing at Shearing Stations* (Kazakh Research Institute of Scientific and Technical Information, Almaty, 1988), 58 pp.
3. *Collection of Abstracts of Research and Development Works of the All-Union Scientific and Technical Information Center*, Series No. 47 (1988), K.U. Medeubekov et al., *Continuous Method of Shearing and Veterinary Processing*.
4. R.N. Marshala, A.F. Burnett, A kinematic, kinetic and electromyographic comparison of stooped sheep shearing techniques and shearing with a sheep manipulator, Appl. Ergon. 35, 137–145 (2004).
5. I.A. Shishina, Results of economic testing of technology and equipment for high-cut wool shearing, in *Improvement of Processes and Technical Means in the Agro-Industrial Complex* (Zernograd, 2000), 2, 99–103.
6. Sham Rane, Varun Grover, Vineet Vashista, Anand Jere, Subir Kumar Saha, Computer-aided analysis of a sheep shearing machine, in *Proc. Nat. Conf. on Emerging Trends in Mechanical Engineering* (SVNIT, Surat, 4–5 June 2007), 1–10.
7. Q.Y. Li, H. Guan, J. Hou, X.R. An, Y.F. Chen, Technical note: transfer of ovine embryos through a simplified mini-laparotomy technique, J. Anim. Sci. 86, 3224–3227 (2008).
8. S.A. Solovyova, M.S. Turgenbaeva, A.N. Rusakova, High-frequency electric shearing unit for sheep, Russ. Agric. Sci. 4, 65–67 (2018).
9. V.V. Kirsanov, D.N. Murusidze, V.F. Nekrashevich et al., *Mechanization and Technology of Livestock Farming* (INFRA-M, Moscow, 2018), 585 pp.
10. Y.Dzh. Osmonov, B.S. Toktonaliev et al., *Mobile Unit for Zooveterinary Processing of Sheep*, Eurasian Patent No. 031780 (Eurasian Patent Organization, 2019), 5 pp.
11. T.L. Saati, *Elements of Queueing Theory and Its Applications* (Soviet Radio, Moscow, 1971), 360 pp.
12. *All-Union Norms for Technological Design of Sheep-Farming Enterprises. SNTP 5-85* (Kolos, Moscow, 1986), 68 pp.
13. Z.T. Andaeva, Study of the system “acaricidal substance–environment”, Bull. Technol. Univ. Tajikistan 4, 14–17 (2017).
14. L. Baylagasov, I. Kapitonova, Issues of preserving the natural environment of the Republic of Altai in the context of agro-industrial complex development, E3S Web Conf. 411, 02060 (2023). DOI: 10.1051/e3sconf/202341102060.