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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy in Technical sciences

IMPROVEMENT OF THE MICRONIZATION TECHNOLOGY AND DEVICE FOR THE CEREAL FORAGE

Specialty: **3102.01 – Agroengineering**

Field of science: **Technical sciences**

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GENERAL DESCRIPTION OF THE RESEARCH

Relevance and degree of completion of the topic. One of the main tasks of animal husbandry at present is to preserve the cattle and increase the productivity of each animal to provide the population with high-quality livestock products. Successful implementation of this task depends primarily on the establishment of a reliable feed base. This, in turn, is possible by the improvement and application of feed production technologies that are not dependent on natural conditions. Especially, the improvement of the use of forage seeds is of great economic importance.

Literature sources indicate that currently, protein deficiency in feeds is 19% higher than acceptable values. As a result, on average, in a feed unit, 85-86 g protein was consumed, instead of 105-110 g of protein required by the zootechnical norm. This protein deficiency causes 30 to 35% loss of product, and the prime cost of the product and the feed consumption increase 1.5 times. The main source of the forage protein is cereals and leguminous plants which provide 50% of all proteins. Therefore, the processing of cereals and leguminous plants in the preparation of fodder is of great importance for using the protein as much as possible. It is known that a big part (40%) of cereal forages is excreted from the organism without digesting. In this regard, different methods of preparation of forage seeds: grinding, steam processing, preparation of ruffled grains, chemical treatment, etc. gain urgency. Recently, the processing of cereals with infrared (IR) radiation of 1500-3500nm, in other words, micronization, has been extensively used.

Currently, micronization is applied in some enterprises preparing groats, instant porridge, and combined feed. However, there are some shortcomings in their use. Heat efficiency is low. For example, if in the perfect variant 50 kW/h is required to heat 1 kg of seeds to 100^{o}C, 130 kWh is required for the best micronizer (efficiency coefficient is 0.26). This can be considered acceptable if the electricity prices are low. However, the observed increase rate in energy prices can limit the application of this method. Such cases have been observed in Western countries. Uneven heating causes differences in the quality indices of the processed grain. This is mainly due to the uneven radiation in the product processing area and the uncoordinated thermophysical and thermoradiation characteristics of the grain material. The heating rate is limited due to the thermal conductivity and temperature gradient in the product.

The constructive and technological improvement of micronizers is necessary for the elimination of these disadvantages. Given the nature of the issues, this research focuses on the technological and constructive improvement of the efficiency of micronizers in the preparation of forage seeds for animal feeding.

The purpose and tasks of the research. The purpose of the study is to substantiate constructive and working parameters to improve the efficiency of the working area in the micronizer.

The tasks of the research include:

- studying physicomechanical, optical and thermophysical properties of seeds to be micronized;
- developing a mathematical model of infrared (IR) heating of seeds;
- theoretical study of the relationship between the temperature of the material, the radiation level and energy consumption in the working area of the high-temperature micronization device;
- experimental study of the thermoactivation process and material exposition conditions;
- experimental comparison of the working zone and different variants of modes;
- testing the modernized high-temperature micronization device under production conditions and determination of its economic efficiency.

Research methods. The objects of the study were forage seeds (their physicomechanical, thermal physical properties), the process of micronization and an experimental micronizer. Theoretical and experimental studies were conducted to achieve the goal. Theoretical studies were carried out using the basic laws of theoretical and applied mechanics, physics, mathematics, and thermal techniques.

Experiments were carried out in laboratory and manufacturing facilities with the help of modern electronic and electromechanical applications, devices, and a developed micronizer. Statistical analysis of the results was performed using computer programs Statistica 10, Mathematica 10, Mathcad 15, Microsoft Excell 13.

Main points presented to the defense of the dissertation:

- mathematical model of the forage seed processing using infrared radiation;
- mathematical expressions of the dependence of thermal and physical characteristics of fodder wheat, barley, maize;
- regularities in changes of optical characteristics of the processed feed material, depending on the wavelength of infrared radiation;
- construction and technological features of the experimental micronizer developed at the level of a utility model;
- substantiated constructive and working parameters in the constructively improved micronizer providing the free flow of seeds and enhancing work quality;
- thermal balance of the experimental micronizer;
- industrial test results and the economic efficiency of the experimental device.

Scientific novelty of the research. The kinetics of the micronization process of forage seeds has been studied, and the dependence of thermophysical characteristics of forage wheat, barley, and maize has been established. Depending on the wavelength of the infrared radiation, changes in the optical characteristics (penetration, reflection and absorption coefficients) of the study objects were clarified. A mathematical model of the process of micronization of the forage seeds has been developed. The model reflects a decrease in the drying rate of the moisture evaporation front as it penetrates the product. The efficiency parameters of the developed experimental micronizer device were substantiated. The experimental micronization device was approved as a Utility model (F 2019 0001) by State Committee for Standardization, Metrology and Patent of the Republic of Azerbaijan, Patent and Trademarks Center of the Azerbaijan Republic, Juridical person, (Az Patent).

Theoretical and practical significance of the research results. Analysis of the IR processing using mathematical modeling of the construction based on the forage seed flow on the vertical cylindrical surface; developing algorithms for the engineering methods of the constructive and regime parameters are of great importance for the theoretical investigations contributing to the improvement of the micronization device.

The application of heat processing in the developed micronizer allows preparing forage seeds according to zoo-technological requirements contributing to the normal digestion of nutrients by animals, improvement of sanitary conditions of fodder leading to an increase in livestock production. The results of theoretical and experimental research can be used in livestock enterprises, research organizations, universities, and agriculture.

Approbation and application of the work. The results of the research were presented at the Scientific-practical conference of the pedagogical collective, postgraduate students and masters of the faculty of "Engineering" of the Azerbaijan State Agrarian University (ASAU) (Ganja, 2014-2018), at the International scientific-practical conference at the Azerbaijan State Agrarian University on "Modern Agrarian Science: Actual Problems and Prospects of the Century in the Context of Globalization" (Ganja, 2014), at the Scientific-Technical Conference on "Actual Problems of Scientific-Technical Progress in Agricultural Production" at the Institute of Agromechanics (Ganja, 2014), at the International scientific-practical conference "Innovative development of agrarian science and education: world experience and modern priorities", at the Azerbaijan State Agrarian University (Ganja, 2015), at the 8th International Scientific-Practical Conference "International cooperation for improving agricultural sciences, food security and environmental protection" at the Azerbaijan State Agrarian University (Ganja, 2016), a lecture was delivered at the Scientific-Technical Council of the Azerbaijan State Agrarian University (Ganja, 2019) and at the 8th International Conference "Science and Society - Methods and Problems of Practical Applications" (Vancouver, Canada, 2019).

The technological line for preparation of forage seeds for feeding using experimental micronizers was offered and it passed production test at the "Araz-T" company in the Tovuz region. The annual efficiency of this line is 4527,2 manats.

Name of the organization where the dissertation was performed: The dissertation work was conducted at Agromechanical Scientific Research Institute

Total volume of the dissertation in characters with an indication of the separate volumes of the structural units. The dissertation consists of the introduction, four chapters, results, the reference list of 170 used literature, and appendices. There are 54 figures, 11 tables and 4 appendices in the dissertation. The introduction consists of 5 pages (10947 characters), the first chapter - 41 pages (76500 characters), the second chapter-35 pages (38107 characters), the third chapter-21 pages (28949 characters), the fourth chapter-29 pages (30989 characters), the results -2 pages (2647 characters), recommendations for producers-1 page (1012 characters) and the reference list of 170 used literature-16 pages (27681 characters). The dissertation consists of 165 pages of computer typing, the total volume is 221491 characters (193854 characters, excluding the list of the used literature and appendices).

CONTENT OF THE WORK

The **Introduction** substantiates the relevance of the topic and presents the general characteristics of the dissertation.

The first chapter is called “Problem setting, research goals, and objectives”. The research status of the methods for the preparation of forage seeds, important features of micronization technology and, critical analysis of the micronizator are presented in this chapter. At the end of the chapter, the goals and objectives of the study are outlined.

During micronization, the carbohydrates in seeds become easily soluble and digestible - gelatinization occurs. The light and thermal energy cause rapid internal overheating (the internal temperature reaches 90^0C in 50 seconds), increasing the water vapor pressure inside the seeds, which swell, burst and their surfaces increase. Such a feed material is in a favorable condition for digestion and its mechanical hardness is weakened. As a result, the useful energy exchange of the forage seed increases. So far, the treatment with infrared (IR) heating has been used in the process of the compound feed preparation for agricultural animals. N.M.Antonov, V.I.Aniskin, Z.T.Adamov, N.Braginets, A.S.Ginzburg, S.V.Zveryev, E.Kosmynin, E.B.Kozin, A.I.Kupreyenko, V.I.Kurdyumov, B.A.Ligidov, N.P.Mishurov, V.F.Nekrashevich, V.A.Novikova, A.A.Rushits, V.I.Syrovatka, Y.P.Tyurev, Kh.H.Gurbanov, and others contributed to the study of the heat treatment of seeds using IR radiation.

N.Y.Braginets, S.V.Zveryev, G.Y.Yegorov, and V.A.Novikova suggested thermal treatment by frying forage seeds. The temperature of the fried surface in such devices is 200 - 230^{0}C. The frying time is 90-100 minutes. During the frying process, the starch is hydrolyzed and converted into dextrin. However, the nutritional value of the combined feed increases slightly.

The modern micronization units are based on conveyor belts. This is due to the fact that the composition of such machines is simple. However, the micronization process is energy-consuming.

Currently, micronization is applied in some enterprises preparing groats, instant porridge as well as combined feed. The industrial application of this method has at least three problems:

1. Low heat efficiency. For example, if in the perfect variant 50 kW/h is required to heat 1 kg of seeds to 100^{o}C, 130 kWh is required for the best micronizer (efficiency coefficient is 0.26). This can be considered acceptable if the electricity prices are low. However, the observed increase rate in energy prices can limit the application of this method;

2. Uneven radiation of the cultivated area, uncoordinated physicothermal and thermoradiation characteristics of the seeds, unequal quality indices of the device;

3. Due to the thermal conductivity of the product and the formation of a temperature gradient, as well as limiting the specific power of the device, the heating rate is limited.

In this regard, to improve the efficiency of the equipment, efforts are being made to modernize the main junctions of the construction and, in particular, to improve the infrared radiation block, which is the main element of the micronizer. However, so far variants with constructively changed seed treatment zones and mode variations have not led to a fundamental change in the construction of the micronizator. Generally, the main focus is on gaining an acceptable level for the product cost and consumption characteristics.

The critical analysis of micronization devices has shown that the use of new perspective methods for the study of the patterns of heat and mass exchange based on the constructive properties of the micronization process will contribute to the high quality of the finished product and developing an efficient micronizator, which effectively use the energetic potential.

The second chapter called "Theoretical Investigation of the Micronization Processes of Forage Seeds" includes the modeling of infrared heat treatment of forage seeds, determination of technological parameters, study of the heat exchange process during micronization, investigation of seed flow, establishment of power required for the dispenser in the construction chosen as a working hypothesis and thermal balance of the device.

A parametric model of the working hypothesis was constructed as follows (figure 1):

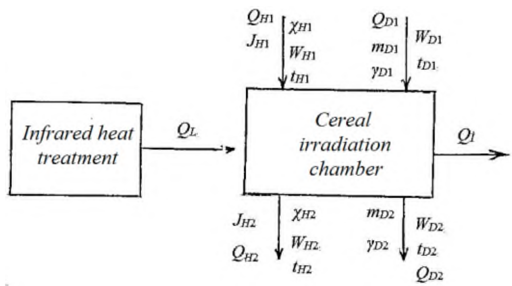


Figure1. Parametric model of the working hypothesis for micronization of forage seeds.

Initial parameters of the forage seed are mass - m_{D1}, temperature - t_{D1}, volumetric weight- γ_{D1}, moisture - W_{D1}, and heat amount Q_{D1}. The atmospheric air enters the device along with the seeds. The parameters of this air are as follows: temperature - t_{H1}, humidity - W_{H1}, moisture content - χ_{H1}, specific enthalpy - J_{H1} and heat amount- Q_{H1}. The amount of heat released by the infrared (IR) lamps affects the seed and its mass changes to m_{D2}, volume -γ_{D2}, humidity -W_{D2}, temperature -t_{D2}, and the amount of heat - Q_{D2}.

The temperature parameters at the outlet are as follows: temperature - t_{H2}, humidity - W_{H2}, moisture content - χ_{H2}, specific enthalpy - J_{H2}, and heat amount - Q_I (a certain amount of heat is lost for micronization).

The principal scheme of the construction chosen for the study based on the working hypothesis is illustrated in figure 2. The ring is connected to the dosing disc having a hole in the bottom. As the seeds are heated and expanded during micronization, the area of the output hole (the space between the quartz glass and the external cylinder) should be larger than the inlet hole (figure 3). In this case, unlike the belt conveyor structures, the place freed from the seed is freely filled.

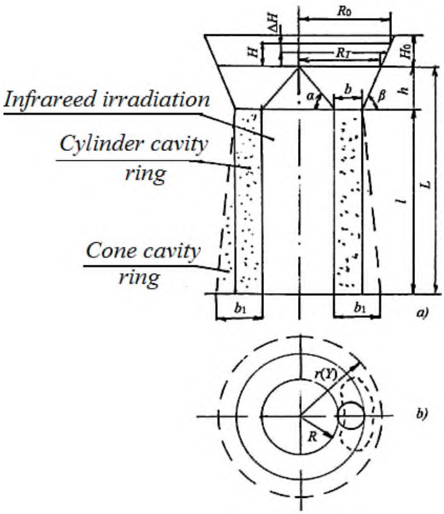


Figure 2. Principal scheme of the micronization device for forage seeds:
a) irradiation chamber b) dosing disc

The volume of seeds passing through the ring-shaped part, where the seeds are heated, increases. The width of the ring should be increased to ensure the free flow of the increased volume. The importance of increasing the width of the ring can be determined by the mass conservation equation.

The volume of the seeds in the entry of the irradiation chamber:

$$dV_0 = \pi r_0^2 dy - \pi R^2 dy. \qquad (1)$$

The volume of the same seed mass in the distance-y:

$$dV(y) = \pi r^2(y) dy - \pi R^2 dy. \qquad (2)$$

Based on the mass conservation law, according to formulas (1) and (2), the ratio of seed volumes is as follows:

$$\frac{dV(y)}{dV_0} = \frac{r^2(y) - R^2}{r_0^2 - R^2}. \qquad (3)$$

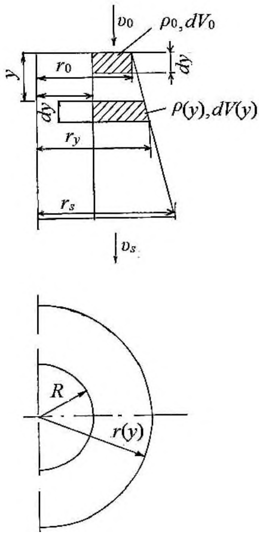


Figure 3. Vertical and horizontal cross sections of the ring-shaped part of the micronizator based on the working hypothesis:

R- internal cylinder radius; $r(y)$ - the radius of the outer wall at the y-distance from top to bottom; ρ_0- density of the forage seeds in y-distance; dV_0- initial volume of the ring at *dy* height; $dV(y)$- volume of the ring having *dy* height in *y* distance.

From the mass equation formula of the selected volumes we derived:

$$dV_0\rho_0 = dV(y)\rho(y),$$

$$\frac{dV(y)}{dV_0} = \frac{\rho_0}{\rho(y)}. \qquad (4)$$

Using formulas (3) and (4) we obtained:

$$\frac{\rho_0}{\rho(y)} = \frac{r^2(y) - R^2}{r_0^2 - R^2}. \qquad (5)$$

Then:

$$r^2(y) = \left(\frac{\rho_0}{\rho(y)} + \frac{R^2}{r_0^2 - R^2} \right) \cdot \left(r_0^2 - R^2 \right). \qquad (6)$$

Based on the linear change of seed density in the radiation chamber:

$$\rho = \rho_S + \frac{\rho_0 - \rho_S}{L}(L - y), \qquad (7)$$

where, L is the height of the chamber for micronization of forage seeds, m.

Using (7) in (6) we obtained:

$$r^2 = \left(\frac{\rho_0 (r_0^2 - R^2)}{\rho_S + \frac{\rho_0 - \rho_S}{L}(L - y)} + R^2 \right). \qquad (8)$$

The radius of the outer ring was found as a function of the y distance:

$$r = \sqrt{\frac{\rho_0 (r_0^2 - R^2) L}{\rho_S L + (\rho_0 - \rho_S)(L - y)} + R^2}. \qquad (9)$$

To analyze equation (9) we calculated the first derivative:

$$\frac{dr}{dy} = \frac{\rho_0 (r_0^2 - R^2)(\rho_0 - \rho_S) L}{\sqrt{\frac{\rho_0 (r_0^2 - R^2) L}{\rho_S L + (\rho_0 - \rho_S)(L - y)} + R^2} \cdot \left[\rho_0 (L - y) + \rho_S y \right]^2}. \qquad (10)$$

From equation (10) we derive:

$$\frac{dr(0)}{dy} = \frac{(r_0^2 - R^2)(\rho_0 - \rho_S)}{\rho_0 r_0 L}. \qquad (11)$$

$$\frac{dr(L)}{dy} = \frac{\frac{\rho_0}{\rho_S}(r_0^2 - R^2)(\rho_0 - \rho_S)}{\sqrt{\rho_0 r_0^2 - (\rho_0 - \rho_S) R^2} \cdot \sqrt{\rho_S} L}. \qquad (12)$$

As can be seen in equations (10), (11) and (12)

$$\frac{dr}{dy} > 0; \qquad \frac{dr(0)}{dy} < \frac{dr(L)}{dy}. \tag{13}$$

This shows that the tangent angle (which is a hyperbolic curve) of the curve *r(y)* will have a positive inclination angle in the direction from the beginning to the end.

Thanks to this form of the irradiation chamber, the seed flow in the ring part of the device is continuous.

Chapter Three is called "Programs and Methods of The Experimental Research". This chapter presents the selection of constructive and technological scheme of the experimental micronizer, its structure and working principles, methods for studying the physical and mechanical properties of seeds. Moreover, this chapter describes the method of optimizing the parameters of the constructive technological mode of the experimental device.

The gap between quartz glass and metal ray reflector-coating ensuring the high efficiency of the micronation process of the forage seeds must be established. In this case, the seed layer should have the minimum thickness and be located between the outer surface of the quartz glass cylinder and the inner surface of the metal ray reflector-coating.

The experiments were carried out at different distances between quartz glass and metal ray reflector-coating (the distance was changed from 5 mm to 15 mm by 1 mm). The experimental device was prepared and the scheme is shown in Figure 4.

The seed micronizer device is schematically depicted in figure 4 (schem 1). Figure 4 (schem 2) illustrates the scheme of infrared radiators inside the quartz glass cylinder. The device consists of 1-body, 2-loading bunker, 3-external cylinder, 4-quartz glass cylinder, 5-radiation chamber between them, 6- infrared radiator, 7-reflector, 8-outlet dosing disc, 9-outlet hole, 10-bunker for processed seeds and 11- electric motor. Radiators-6 and reflector-7 are assembled as lower-14 and upper-15 cassettes. The external cylinder (3) equipped with the loading bunker (2) is located inside the body (1) and a quartz glass cylinder (4) is located inside the external cylinder and centers of these cylinders are overlapped. Infrared radiators (6) are placed vertically as cassettes inside the quartz glass cylinder (4).

They are equipped with a ray reflector (7). The outlet hole (9) emerges in the lower part of the cylinder when the position of the outlet dosing discs (8) changes. Passing through the outlet hole (9) processed seeds are collected in the bunker (10). The outlet dosing disc (8) is equipped with a speed adjustable electric engine (11). The quartz glass cylinder (4) is equipped with a guide cone (12) inside the loading bunker (2), which has a lid (13).

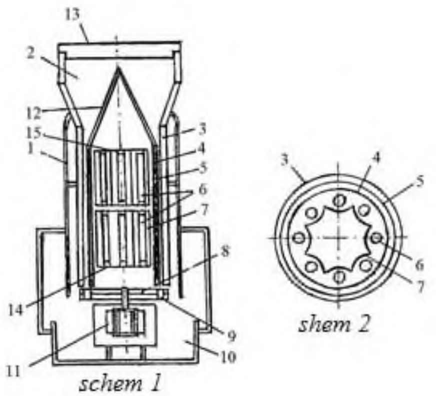


Figure 4. Scheme of the experimental micronizer device:
1-body; 2- loading bunker; 3- external cylinder; 4- quartz glass cylinder; 5-radiation chamber; 6- infrared (IR) radiator; 7- reflector; 8- outlet dosing disc; 9-outlet hole; 10- bunker for processed seeds; 11-electric engine; 12-guide cone; 13-lid; 14-lower cassette; 15-upper cassette.

The seed micronization device works as follows: Seeds purified from dust and contaminations are placed in the loading bunker (2). They fill the gap (radiation chamber-5) between the external cylinder (3) and the quartz glass cylinder (4). At that time the outlet hole (9) is closed because the outlet dosing disc is also closed. But IR radiation (9) is switched on. The electric engine (11) is launched when the required exposition is reached. The outlet dosing disc (8) starts up, processed seeds pass through the outlet hole (9) and are collected in the bunker (10). The outlet hole (9) opens beforehand in a size corresponding to the required productivity. The IR radiators (6) and quartz glass cylinder (4) assembled as cassettes (14, 15) are hanging on the lid (13).

The application of the proposed device will save considerable energy based on the maximum efficient use of the radiation heat in the micronization process. The constructive innovation of the device was approved by the Patent and Trademark Center of the Republic of Azerbaijan as a utility model (U 20170025). Wheat, barley and, oat were used for the experiments. Their humidity was 14-15%. Seeds were pre-cleaned from small, light and long size impurities.

A multi-factor experiment was conducted to determine the optimum distance between the IR radiation lamp and the quartz glass and the optimum power of the light flow. The experiments were performed on an experimental device equipped with the Legrand dimmer, which allows changing the radiation power of the lamps. The obtained results were analyzed using the program Statistica 6.0.

The title of **Chapter Four** is Results of Experimental Studies. Physicomechanical, optical and thermophysical properties of the forage seeds, technological and structural parameters of the experimental micronizer, the optimization of constructive and regime parameters of the device, substantiation of the device productivity, and estimation of the economic efficiency of the experimental micronizer device were presented in this chapter.

Without studying the thermophysical characteristics of the seed production (coefficient of thermal conductivity –λ-W/m$\cdot$K, transfer of temperature *a*- m^2/s, specific heat capacity *c*- Joule/kg$\cdot$K), it is impossible to study their micronization process. Thermophysical characteristics of forage seeds were studied using the Coesfeld RT-1394H apparatus. The measurements were taken at the temperature range of 20-80^{0}C (table 1).

For the processing of the experimental results, the programs labWiew 7.0 and “Microsoft Excel 2010” were used. The following equations relate to thermophysical characteristics of wheat at the temperature range of 20-80^{o}C.

For the initial humidity of forage seeds:

$$a= -0.0471T+18.75;\ R^2=0.9987; \quad (14)$$

$$\lambda=0.0015T+0.3165;\ R^2=0.9857; \quad (15)$$

$$c=18.341T+1837.6;\ R^2=0.995. \quad (16)$$

For the final humidity of forage seeds:

$$a= -0.042T+17.28;\ R^2=0.9972; \quad (17)$$

$$\lambda=0.0018T+0.2275;\ R^2=0.99; \quad (18)$$

$$c=20.213T+1362.7;\ R^2=0.993. \quad (19)$$

Table .Thermophysical characteristics of wheat

No	t °C	Samples of forage seeds					
		Before the processing (density ρ=871.3 kg/m^3)			After the processing (density ρ=895.7 kg/m^3)		
		a	λ	*c*	*A*	λ	*c*
1	20	17.80±0.15	0.345±0.004	2217.56±0.10	16.48±0.15	0.267±0.004	1802.62±0.15
2	40	16.91±0.15	0.373±0.004	2532.08±0.15	15.57±0.15	0.294±0.004	2107.52±0.15
3	60	15.87±0.2	0.411±0.004	2976.75±0.15	14.69±0.15	0.341±0.004	2595.78±0.10
4	80	15.01±0.15	0.430±0.004	3292.07±0.10	13.97±0.2	0.373±0.004	2987.43±0.15

Using the multi-factor experiment, the distance between the object and lamps, the thickness of quartz glass and the light power were optimized in accordance with the micronization level (sufficient micronization). For this purpose, the method of the planning experiment was applied. Time (*t*, sec) required for sufficient micronization of seeds was taken as the optimization criterion.

The Box-Behnken second order, rotatable, composite design was chosen for the experiments. The study was performed on wheat, barley, and oat. The effect of the quartz glass thickness (δ) and the distance between the object and the IR radiation lamp on the time (*t*) of micronization is presented in figure 5. During the experiments, the IR radiation lamp power was 1 kW.

Using the method of Mathematical statistics for processing the results, a mathematical expression of the effect of thickness of the quartz glass (δ) and the distance between the object and the lamp (b) on the time (t) spent for micronization of seeds was established:

$$t=178.1944-1.2708\delta-30.9375b+0.0021\delta^2+0.2813\delta b+1.4583b^2. \quad (20)$$

The relevance of the study was examined using statistic analysis. The adequacy of the derived equation was evaluated by the Fisher criterion. It was confirmed that the equation quite exactly expressed the studied dependencies.

As seen in figure 5, when the lamp power is 1kW, the optimum parameters for micronization are δ=6 mm (thickness of the quartz glass) and b=50mm (the distance between the lamp and the object). Under these conditions, the time required for wheat micronization is 80 seconds.

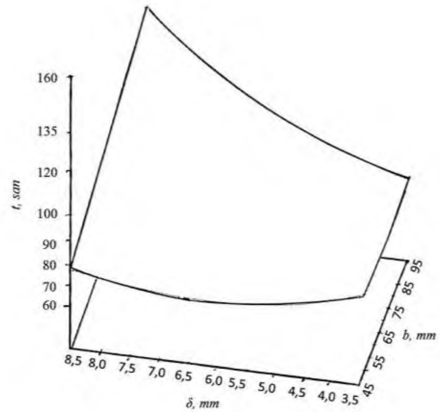


Figure 5. Effect of the quartz glass thickness *(δ)* and the distance between the object and the lamp *(b)* on the time *(t)* spent for micronization of wheat seeds.

The effects of the quartz lamp thickness (*δ*) and the power of IR radiation lamp (N_{lam}) on the micronization time (*t*) were determined (figure 6).

The distance between the lamp and the object was *b*=50 mm. The equation expressing the effect of the quartz lamp thickness *(δ)* and the IR radiation lamp power *(N_{lam})* on the micronization time *(t)* was derived as a result of the statistical processing of the experimental results:

$$t = 597{,}9167 + 25{,}2083\delta - 1305N_{lam} - 0{,}625\delta^2 - 17{,}58N_{lam} + 760N_{lam}^2. \quad (21)$$

The equation expressing the effect of the quartz lamp thickness *(δ)* and the IR radiation lamp power *(N_{lam})* on the micronization time *(t)* was derived as a result of the statistical processing of the experimental results:

$$t = 597{,}9167 + 25{,}2083\delta - 1305N_{lam} - 0{,}625\delta^2 - 17{,}58N_{lam} + 760N_{lam}^2. \quad (21)$$

The obtained equation demonstrates the studied thermal process and is usable in practice.

As seen in Figure 6, the following parameters can be considered as optimal for wheat seed micronization: the quartz glass thickness δ=6 mm, the IR lamp power N_{lam}=1.0 kW

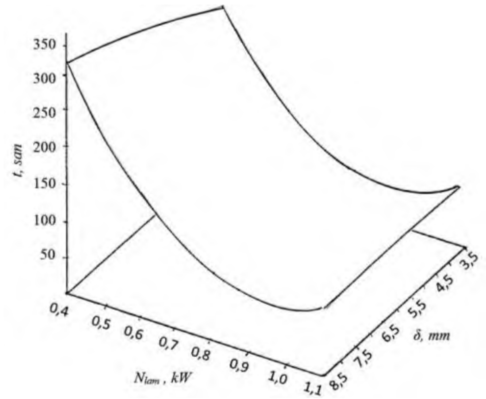


Figure 6. The combined effect of the quartz lamp thickness (δ) and the IR radiation lamp power (N_{lam}) on the micronization time (t).

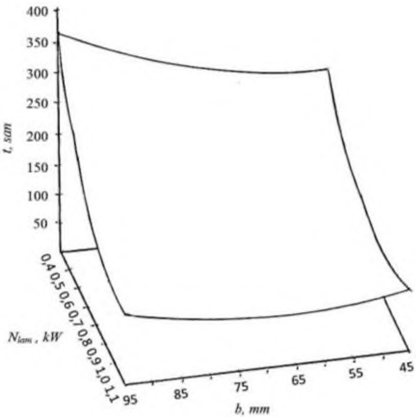
The combined effect of the distance (b) between the IR radiation lamp and the object and the lamp power (N_{lam}) on the micronization time is presented in figure 7.

The thickness of the quartz glass during the experiments was δ=6 mm. The following equation was derived as a result of the statistical processing of the experimental results:

$$t = 648{,}2639 - 2{,}0417b - 1055N_{lam} + 0{,}0354b^2 - 2{,}5bN_{lam} + 626{,}6667N_{lam}^2. \quad (22)$$

The obtained equation (figure7) demonstrates the studied thermal process and is usable in practice. As seen in figure 7, the following parameters can be considered as optimal for wheat seed micronization: the distance between the lamp and the object b=70 mm, the power of the IR lamp N_{lam}=1.0 kW.

The economic efficiency of the experimental micronizer has been established. When using the improved micronization device, the economic benefit for an enterprise with an annual capacity of 380.12 tons, is 4527.2 manat.



Figiure 7. The combined effect of the distance (*b*) between the IR radiation lamp and the object and the lamp power (N_{lam}) on the micronization time.

The results of the research were discussed and approved by the Scientific and Technical Council of the Azerbaijan State Agrarian University and recommended for the industrial applications.

Results

1. The analysis of modern technology for the forage seed processing and performed experiments showed that the technology of the preparation of combined feed can be improved by applying micronization.
2. As seeds become swollen when passing through the hole of the radiation chamber, the outer reflective coating should be in the form of a cone expanding toward the dosing disc.
3. The mathematical model of the forage seed heating by IR radiation was developed and the possibility of using ray reflector surfaces in the zone of seed processing was substantiated. It was found that the efficiency of the micronizator depended on the radius and length of the internal cylinder, the IR radiation lamp power and

the duration of the stay of seeds between the internal cylinder (quartz glass) and reflective coating.

4. Theoretical and experimental studies revealed that the proper choice of the density of light flow and time of the seed treatment could result in a significant decrease in the moisture of the seed cover and nucleus.

5. According to the results of the experiments, when the temperature increased from 20^{o}C to 180^{o}C, the coefficient of friction of grains on quartz glass changed as follows: in wheat, barley and oat in the ranges of 0.296- 0.264, 0.401-0.253, and 0.334 - 0.284, respectively. When temperature increased from 70^{o}C to 150^{o}C, the heat transfer coefficient changed as follows: in wheat, barley and oat in the ranges of 3.72- 2.16 m^2/s, 4.48-3.66 m^2/s and 4.4- 2.1 m^2/s, respectively. Thermal conductivity for wheat, barley, and oat was found to change in the ranges of 6.31- 3.301 W/m^{o}C, 7.77- 5.425 W/m^{o}C and7.149- 2.994 W/m^{o}C, respectively.

6. Destructive force for 50 grains (350-450 N) can be used to characterize qualified micronization. Laboratory studies have identified the following: the distance between the internal cylinder (quartz glass) and metal ray reflector should be 7-9mm to ensure free passing for forage seeds. The thickness of the quartz glass should be 6mm and the distance between the IR radiation source and the internal surface of the quartz glass cylinder should be 50 mm.

7. To provide the micronizer productivity of 0.2-0.22 tons/ha, the dosing disc rotation rate of 118.75 min^{-1}, the dosing hole surface of 0.241x10^{-3} m^2 and the power of the IR radiation lamp of 1 kW are required.

8. The use of the improved micronization device saves energy by 14% due to the most efficient use of radiation heat in the micronization process. The economic profit for an enterprise with a capacity of 380.12 tons per year is 4527.2 manats.

Recommendatıons for producers

Livestock and poultry producers are advised to apply micronization for the economical and efficient use of forage seeds obtained from their feed source.

The results of the field tests and the data presented in the general results of the dissertation can be used by farmers for increasing the efficiency of the micronizator.

The mathematical model substantiating the working process of the constructively improved micronizator, constructive-technological parameters confirmed by practice can be used in constructor offices of industrial facilities planning to produce and improve devices performing thermal processing of the production with IR radiation.

The obtained constructive requirements for the improvement are advisable to include in the tutorials.

The main points of the dissertation are presented in the following articles:

1. Mammadov N.Kh. Determination of the technological parameters in the treatment of combined feed with IR radiation// Materials of the International scientific –practical conference on “Modern agrarian science: Actual problems and prospects of development in the context of globalization ”, - Ganja, ASAU, - 2014. Vol 2, - p.83-84 (in Azerbaijani).

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6. Mammadov N.Kh. The study of micronization of the flat seed layer//Materials of the 8th International scientific-practical conference on “International cooperation in the development of

agrarian science, food security and environmental protection", Ganja: ASAU, - 2016. Vol 2, - p.252-254 (in Azerbaijani).

7. Mammadov N.Kh. The study of the thermophysical and optical properties of forage seeds//Azerbaijan Agrarian Science, - 2016. - No2, - p.113-115 (in Azerbaijani).

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13. Mammadov N.Kh., Salmanova K.A. Thermal balance of the micronization device during seed processing with infrared radiation // 8th International conference Science and society – Methods and problems of practical application, Vancouver, Canada, - 15th august, - 2019, - p.92-98.

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