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Research on the Work Process of a Station for Preparing Forage

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Abstract: Forage from grain plays a special role in animal nutrition because it constitutes feed with a high content of readily available carbohydrates. Unfortunately, the equipment used to prepare forage is often manufactured without the necessary justification and confirmation of the declared sizes and indicators of the work process. This forms the basis for our theoretical and experimental studies. Research has been carried out to provide justification of the design and operating parameters of the patented station for producing forage from cereal crops. This article describes the technology for preparing forage from grain and provides a detailed description of the station used and the principle of its operation. During the experiments, we studied the influence of the angle α of setting the grid-work (plate) and the distance S from the nozzle to the grid-work on the quality of forage. Qualitative, quantitative, and energy indicators have been evaluated using up-to-date measuring instruments and equipment. The method is described, and the studied factors and evaluation criteria for the preparation of forage from grain are indicated. The forage quality results are presented, as determined by the content of whole grains in it via the residue on a sieve with a sieve size of 3 mm when preparing it with a different combination of the studied factors. The analysis of the energy consumption results of the process of preparing forage from grain under various operating conditions of the plant is shown. As a result, the optimal location parameters of the passive grinder have been found, allowing to obtain high-quality forage with minimal power consumption of the electric motor. A grid-work should be used as a grinder. Its installation angle should be 30°, and the distance between the grid-work and the nozzle should be 205 mm. With this combination of parameters, the specific energy consumption is minimal and amounts to 41.5 W·h/L.

Keywords: forage from grain; cereal grain; energy consumption

1. Introduction

Obtaining high performance indicators for farm animals is determined by a scientifically validated diet and feeding regime, which must include properly processed cereal grains [1–6]. Preparation of feed directly on the farm will give a positive result if a producer has his/her own grain raw materials. With this knowledge, agricultural producers are trying to find feed preparation equipment that is optimal in terms of quality and quantity, separately or as part of a line, depending on the volume of production [7].

These are mainly crushers or flatteners for producing dry concentrates, which are the most known and proven [8–13]. However, studies show that processing carried out using this type of equipment does not ensure full utilization of the energy value of the grain [11–17]. As previous studies [16,18–22] show, it is possible to obtain feed in the form of forage from grain with a high content of readily available carbohydrates (this kind of feed has great value, primarily for dairy cows). Unfortunately, corresponding equipment is manufactured for such needs without the necessary justification and confirmation of the declared sizes and indicators of the work process [21–24]. Recognizing the practical importance of addressing these issues, theoretical and experimental studies have been carried out to provide justification for the design and operating parameters of the plant for producing forage from cereal crops on the basis of an agreement between the leading manufacturer of animal feed equipment "Doza-Agro" LLC and the Nizhniy Novgorod State Engineering and Economic University (NNSEEU). The article presents the data reflecting the key research insights obtained in the framework of R&D.

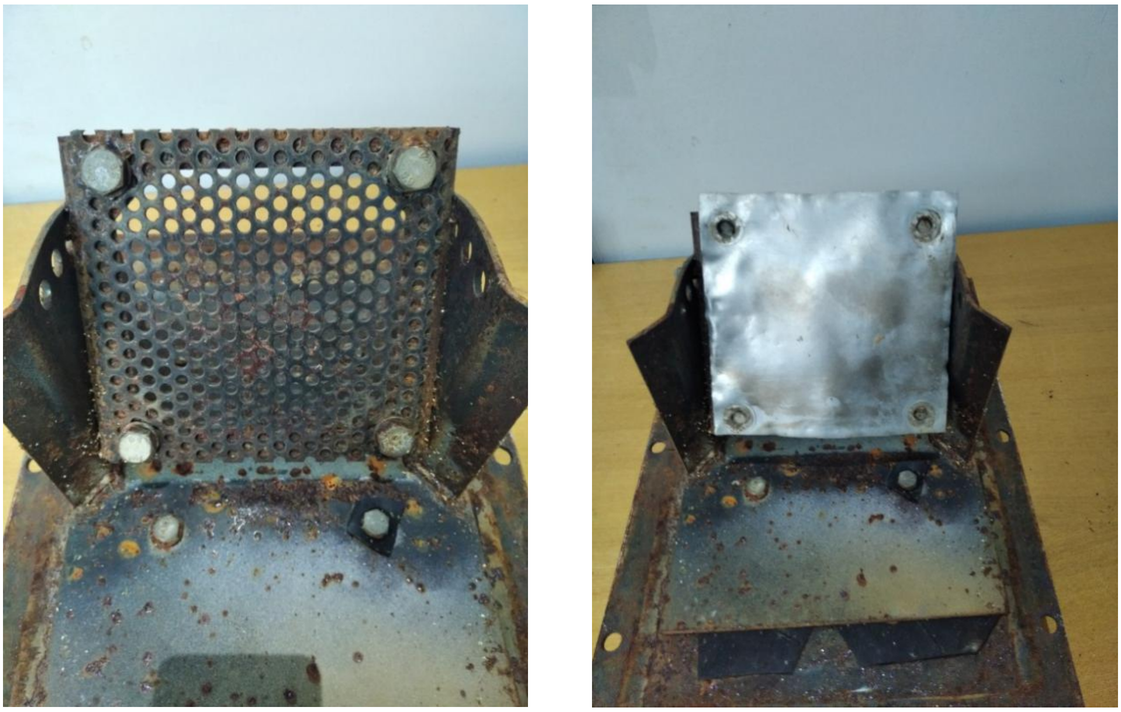
2. Materials and Methods

To study the process of preparing forage from grain, a laboratory-scale plant has been developed consisting of a frame on wheels, a tank with a built-on passive grinder, a 1SM65-50-160/2 centrifugal pump and a NGD-1.1 disperser, material pipelines, and a control cabinet (Figure 1). The measuring station operates as follows. Water is poured into the tank based on the required volume of prepared forage at the outlet, which is 2:1 with respect to the grain. The amount of water poured was recorded by a water meter SVK 15-3-8 (Figure 2). Next, the centrifugal pump is turned on, and the heating process to 30 °C takes place. When this temperature is reached, the tank is uniformly filled with pre-processed and cleaned grain at the given water:grain ratio. Next, enzymes are added. Through special inspection ports in the built-in grinder (chopper), the uniformity and homogeneity of the working mass are visually monitored, and, upon reaching a temperature of 60 °C, the pump is switched off. The prepared mass is allowed to infuse for one hour for the more efficient operation of enzymes. The result is a high-carbohydrate forage from grain recommended for feeding farm animals as a single feed or as a part of feed mix.

Figure 1. The measuring station for preparing forage from grain.

Figure 2. Water meter SVK 15-3-8 used for recording the amount of water poured into the tank of the measuring station.

While the plant pump is operating, the grain is crushed by its blades. To accelerate the process of grain grinding and to obtain a more even forage composition, it was proposed to install a passive grinder in the form of a grid-work (grill) or a plate in the upper part of the tank (Figure 3). During the experiments, the influence of the angle α of setting the grid-work (plate) and the distance S from the nozzle to the grid-work (Figure 4) on the quality of forage have been studied. It was modified by moving the grid-work (plate) between the holes of the fixture of the laboratory-scale plant (Figure 5). The distance S between the grid-work (plate) and the nozzle was adjusted by moving the grid-work (plate) along the slots in the cover (Figure 6).



a b

Figure 3. Passive grain grinder made in the form of (**a**) grid-work and (**b**) plate.

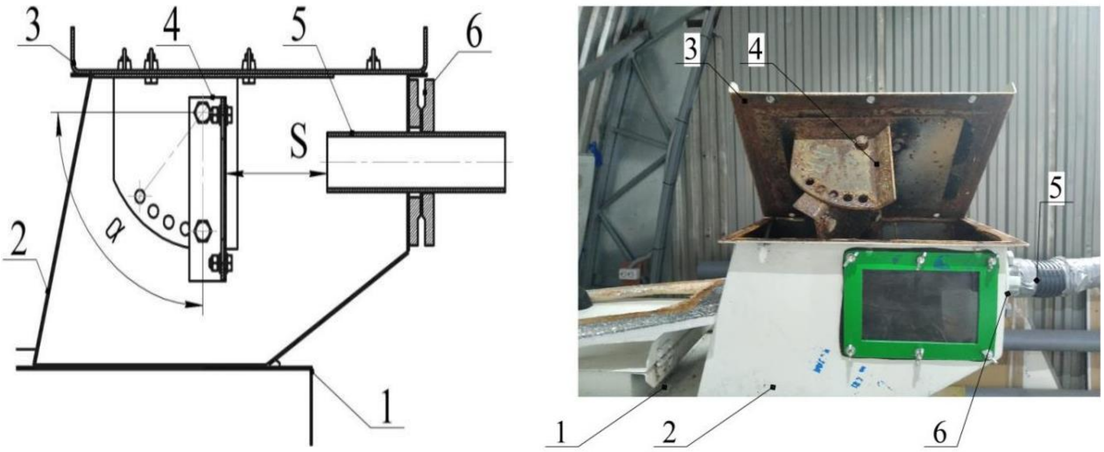


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Figure 4. A device for adjusting the inclination angle of the grid-work (plate) and its distance to the nozzle. (**a**) Diagram; (**b**) General vie: (1) tank with a built-in passive grinder, (2) case of the passive grinder, (3) cover of the passive grinder, (4) grid-work (plate), (5) nozzle, (6) nozzle flange.

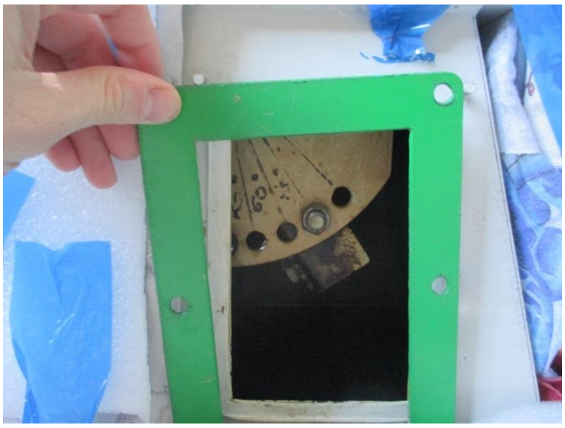

Figure 5. The system for adjusting the inclination angle of the grid-work (plate).

Figure 6. Cover with slots for adjusting the clearance S between the grid-work (plate) and the nozzle.

To determine the performance of the proposed plant under scientific laboratory conditions, a technique was developed to assess the influence of design and operating parameters on the work process of preparing forage from grain. Wheat was used as the source raw material. To carry out the fermentation process, the multi-enzyme composition MEC-AC-3 produced by Vostok LLC, Kirov Region (Russian Federation), was used. The volume of forage prepared was 50 L.

Routine of the experiment was as follows. First, 17 kg of grain was put into 33 L of water pre-heated to a temperature of 30 °C, and 80 g of enzyme was added, previously weighed with the accuracy of up to 0.01 g using the Biomer VK-300.01 laboratory balance (Novosibirsk) (Figure 7). From that moment, the process timing began using the HUAWEI P20 lite stopwatch (China). Every 7 min 30 s before the working mass temperature reached 60 °C, a test batch was taken from the tank: the tank cover was opened, and a 1 L volume bucket was placed under a stream and filled up. Within the same time intervals, in addition to recording the temperature values, the power consumed by the pump electric motor was recorded using the Mastech MS2203 clamp meter (Pittsburg U.S.) (Figure 8). After that, the feed sample was poured onto a sieve with a sieve size of 0.5 mm. Free water was removed by vigorous stirring with a brush. The resulting mass was poured into a plastic bag, which was assigned an information tag (Figure 9). Three to five packets with samples were obtained before the temperature reached 60 °C. After that, the pump was turned off, and one hour was timed until the forage from grain was completely prepared.

Figure 7. Weighing the multi-enzyme composition MEC-AC-3 using the VK-300.01 laboratory balance.

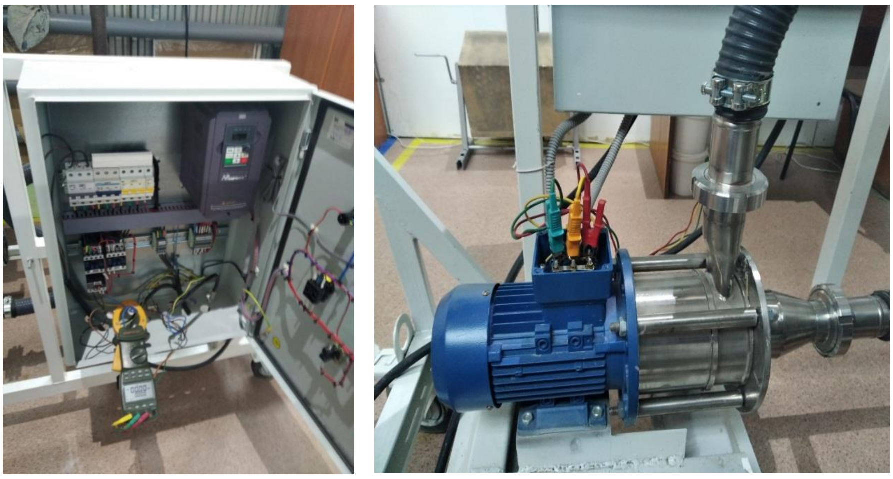

Figure 8. Measuring the power consumption of the electric motor using the Mastech MS2203 clamp meter.

Figure 9. Bags with samples of forage from grain.

Temperature of the forage from grain (and water) was recorded using the TST81 sensor, the data from which was transmitted to the TL-11-250 temperature controller (Figure 10). During the experiment, the dynamics of temperature changes was recorded from the digital display of the temperature controller (Figure 10).

a b

Figure 10. Temperature controller TL-11-250 with a temperature sensor TST81 (**a**) and recording the temperature of the forage from grain (**b**).

Next, a 100 g sample weight was selected from each bag and distributed on the sieve with a sieve size of 3 mm. After that, the sample was rinsed out in a bath with water. Next, the sieve residue was weighed, and the number of whole grains was counted.

An hour later, a control sample was taken from the premixed forage from grain. To determine the uniformity, screen sizing was collected using sieves of the following sizes: 2; 1.4, 1; 0.5 mm and the bottom. Then, 100 g of the sample weight was fed to the upper sieve, and then the plansifter (RL brand) was turned on for 5 min (Figure 11). First, the dry sieves were weighed, and their mass was determined. Then, they were weighed with the residue, and the difference was determined. For best data reliability, this analysis was performed in triplicate.

Figure 11. Laboratory plansifter RL brand with a set of sieves for determining the granulometric composition of the forage.

For energy estimation of the plant operation, specific energy consumption was used referred to a unit volume of the working mixture, w1:

$$\mathrm{w1} = \frac{\mathrm{W} \cdot \tau}{V}, \quad (1)$$

where

W is the average power consumption, kW;
τ is the process time, s;
V is the volume of water and working mixture, l.

3. Results

After the experiments, tables and graphs were constructed that characterize the change in the quality of forage from grain depending on the installation parameters (α and S) of the grid-work and the time t of the fermentation process (Tables 1 and 2, Figures 12–15). According to the results of experiments and calculations according to the formula (1), histogram 16 was constructed. Histogram 16a shows what full electric motor power is spent on preparing the forage. Figure 16b presents the change in the specific costs of electricity calculated using the expression (1). The constructed histograms show how the power consumption of the electric motor changes when the angle α of setting the grid-work (plate) and the distance S between the grid-work (plate) and the nozzle are modified.

Regardless of the angle α of setting the grid-work and the distance S, the number of whole grains decreases to 0 after 1350 s (22.5 min) of the plant operation (Figure 12). After 900 s (15 min) of the plant operation, the minimum number of whole grains is observed when the grid-work is installed according to options 1 and 3 (Figure 12). That is, according to the indicator m1 "the number of whole grains in the forage," we can recommend the grid-work installation scheme using options 1 and 3.

The number of whole grains reaches the value of 0 in 1350 s (in 22.5 min) when the plate is installed at an angle α = 90° at S = 140 mm (Figure 13). In other cases, in order to avoid the presence of whole grains in the forage, the operation time of the plant should be at least 30 min. The graph also shows that with decreasing angle α, the number of whole grains in the forage increases. This is explained by the fact that, when the angle α is decreased, the impact force of the grain on the plate goes down. From the analysis of the graphs presented in Figure 13, we can conclude that the best results of preparing forage using a plate are obtained when it is installed according to options 3, 4, and 5 (Figure 13).

The best performance in terms of the indicator "residue on the sieve with a sieve size of 3 mm" is also achieved when the plate is installed according to options 3, 4, and 5 (Figure 14). In these cases, the m2 indicator is close to zero after 1800–1850 sec of the plant operation. When the plate is installed at an angle of 30 and 45° for a time t = 1800 s, m2 equals 0.1% and 0.4%, respectively, and a zero value is reached only after 2080 and 1989 s, respectively. That is, in terms of the indicator "residue on a sieve with a diameter of 3 mm," it can be recommended to prepare forage when the plate is installed according to options 3 and 5.

The average power consumed by the engine while preparing forage did not exceed 5 kW. The lowest value was recorded when the grid-work was installed at an angle of 30° and at a distance of 205 mm from the nozzle—it was 4 kW. In general, the average engine power during the preparation of forage using a grid-work is lower than when using a plate. When using the grid-work, it did not exceed 4.5 kW, and when using the plate, it varied from 4.51 to 5 kW (Figure 16a).

Change in specific energy consumption required to prepare 1 L of forage from grain is shown in Figure 16b. In general, it can be seen that when a grid-work is used, the specific energy consumption is lower than when a plate is used. Based on the findings presented, we can recommend the use of a grid-work installed at an angle of 30° at a distance of 140 and 205 mm from the nozzle, or a plate installed at an angle of 90° at a distance of 140 mm from the nozzle. With this combination of parameters, the minimum specific energy consumption is observed, which amounts to 41.5–48.4 W·h/L. In other cases, there is an increase in this indicator to 50–52 W·h/L (Figure 15c).

Table 1. The change in the quality of forage from grain depending on the installation parameters (α and S) of the grid-work (where M is average, SD is standard deviation, and SKE is skewness factor).

Czas [s]	Number of whole grains in molasses when prepared using a grid-work (pcs.)			The residue on the sieve with a sieve size of 3 mm when prepared using a grid-work (%)		
	M	SD	SKE	M	SD	SKE
1—distance from the grid-work to the nozzle is 140 mm, grid-work inclination angle is 30 degrees						
450	916	5.18	−0.68	35.95	0.95	0.18
900	1	0.63	0	0.8	0.13	0
1350	0	0	0	0.1	0.05	0
1800	0	0	0	0	0	0
1857	0	0	0	0	0	0
2—distance from the grid-work to the nozzle is 140 mm, grid-work inclination angle is 45 degrees						
450	780	2.9	0.73	28.81	2.21	−0.01
900	2	0.63	0	1.17	0.07	−0.06
1350	0	0	0	0.43	0.1	0
1800	0	0	0	0	0	0
1984	0	0	0	0	0	0
3—distance from the grid-work to the nozzle is 205 mm, grid-work inclination angle is 30 degrees						
450	255	2.28	−0.91	7.45	0.69	−0.6
900	1	0.63	0	0.75	0.05	−1.1
1350	0	0	0	0.17	0.01	0
1800	0	0	0	0.01	0	0
1998	0	0	0	0	0	0
4—distance from the plate to the nozzle is 205 mm, grid-work inclination angle is 45 degrees						
450	653	3.52	−0.61	24.26	2.21	0.19
900	4	1.67	−1.15	1.55	0.18	−0.6
1350	0	0	0	0.07	0.01	0
1800	0	0	0	0.01	0	0
1878	0	0	0	0	0	0

Table 2. The change in the quality of forage from grain depending on the installation parameters (α and S) of the plate (where: M—average, SD—standard deviation, SKE—skewness factor).

Czas [s]	Number of whole grains in molasses when prepared using a plate [pcs.]			The residue on the sieve with a sieve size of 3 mm when prepared using a plate [%]		
	M	S	SKE	M	S	SKE
1—distance from the plate to the nozzle is 140 mm, plate inclination angle is 30 degrees						
450	615	68.77	0.56	51.21	4.86	−0.81
900	56	10.53	0.68	2.7	0.21	0.47
1350	20	3.16	0	0.59	0.04	0
1800	0	0	0	0.4	0.08	0
2080	0	0	0	0	0	0
2—distance from the plate to the nozzle is 140 mm, plate inclination angle is 45 degrees						
450	41	4	0.98	28.29	1.16	−0.44
900	9	2.28	1.21	4.9	0.3	−0.19
1350	2	0.63	0	0.67	0.06	0
1800	0	0	0	0.09	0.02	0
1989	0	0	0	0	0	0
3—distance from the plate to the nozzle is 140 mm, plate inclination angle is 90 degrees						
450	680	41.42	−2.13	44.53	3.55	−0.85
900	3	1.1	1.36	1.02	0.13	−0.1
1350	0	0	0	0.08	0.02	0
1800	0	0	0	0.04	0	0
1851	0	0	0	0.01	0	0
4—distance from the plate to the nozzle is 205 mm, plate inclination angle is 90 degrees						
450	400	4.69	−0.26	400	15.61	0.72
900	5	2.76	−0.09	5	1.67	−0.38
1350	1	5.18	0	1	0.46	0
1800	0	2.83	0	0	0	0
1852	0	6.42	0	0	0	0
5—distance from the plate to the nozzle is 305 mm, plate inclination angle is 90 degrees						
450	400	1.41	2	400	17.52	1.93
900	12	4.05	3	12	2.53	2.1
1350	1	4.69	4	1	0.38	−0.25
1800	0	3.85	5	0	0	0
1852	0	7.21	6	0	0	0

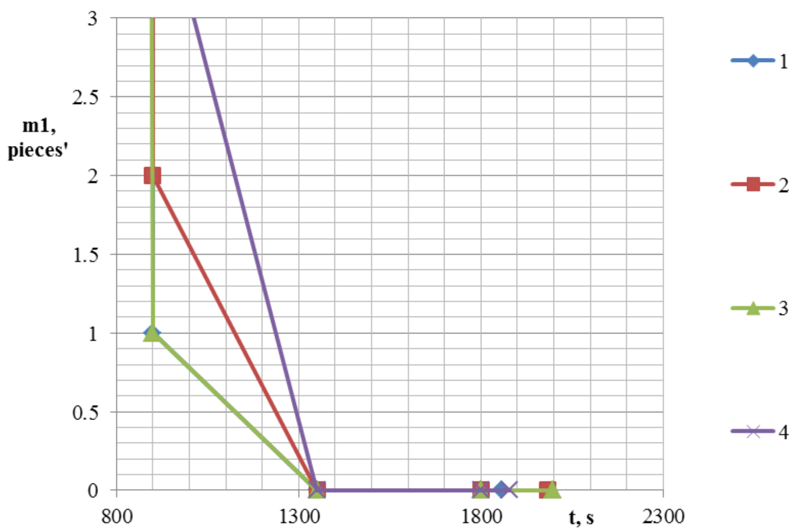

Figure 12. Number of whole grains in molasses when prepared using a grid-work: 1—the distance from the grate to the nozzle is 140 m the angle of inclination of the grate is 30 degrees; 2—the distance from the grate to the nozzle is 140 mm, the angle of inclination of the grate is 45 degrees; 3—distance between the grate and nozzle 205 mm, angle of inclination of the grate 45 degrees; 4—distance between the grate and nozzle 205 mm, angle of inclination 30 degrees.

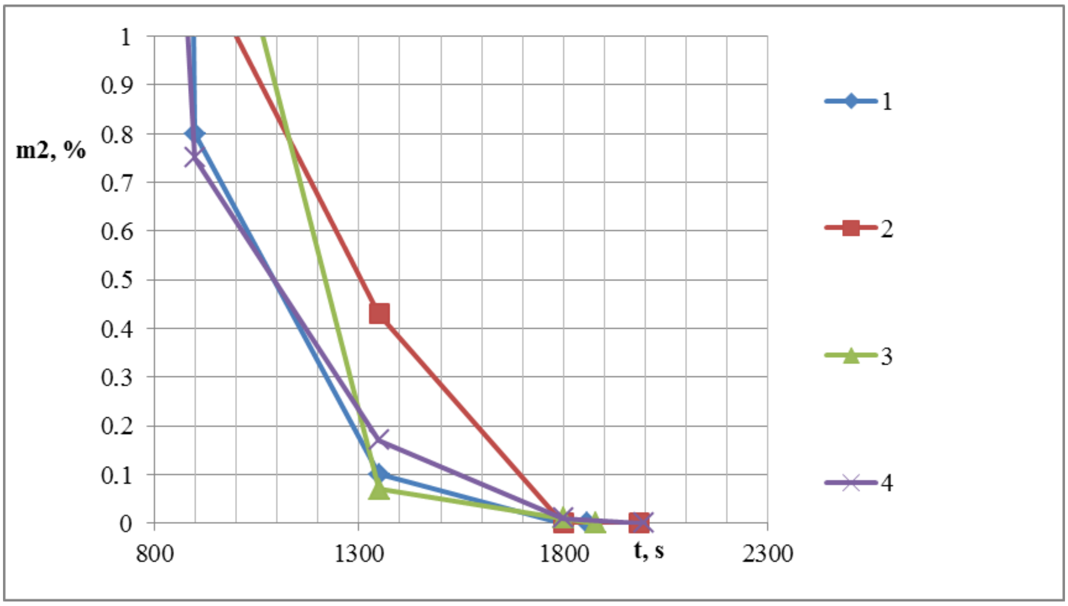

Figure 13. The residue on the sieve with a sieve size of 3 mm when preparing forage using a grid-work: 1—distance from the grid-work to the nozzle is 140 mm, grid-work inclination angle is 30 degrees; 2—distance from the grid-work to the nozzle is 140 mm, grid-work inclination angle is 45 degrees; 3—distance from the plate to the nozzle is 205 mm, grid-work inclination angle is 45 degrees; 4—distance from the grid-work to the nozzle is 205 mm, grid-work inclination angle is 30 degrees.

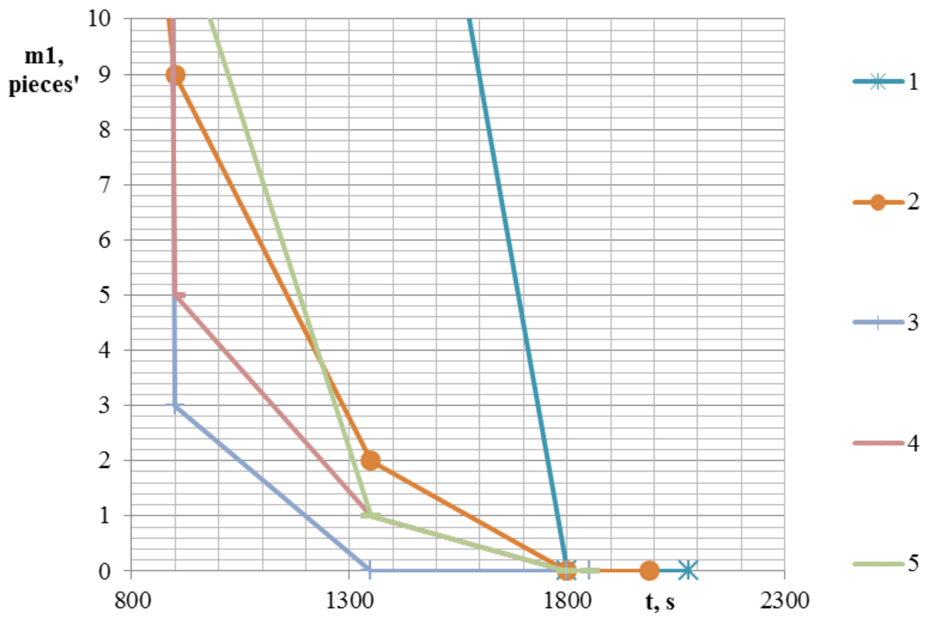

Figure 14. The number of whole grains in forage when it is prepared using a plate: 1—distance from the plate to the nozzle is 140 mm, plate inclination angle is 30 degrees; 2—distance from the plate to the nozzle is 140 mm, plate inclination angle is 45 degrees; 3—distance from the plate to the nozzle is 140 mm, plate inclination angle is 90 degrees; 4—distance from the plate to the nozzle is 205 mm, plate inclination angle is 90 degrees; 5—distance from the plate to the nozzle is 305 mm, plate inclination angle is 90 degrees.

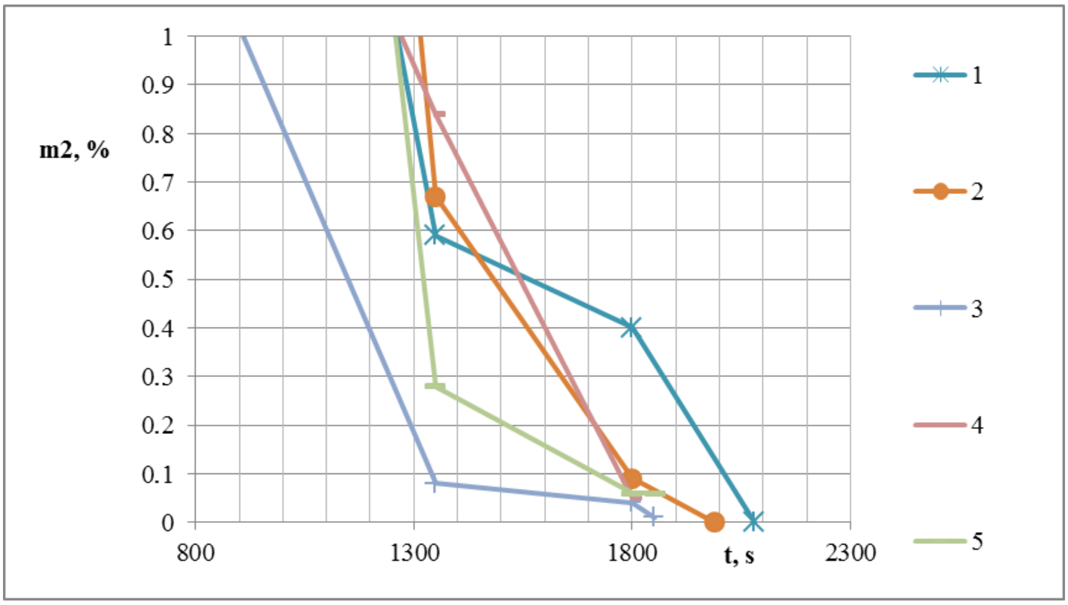

Figure 15. Residue on the sieve with a sieve size of 3 mm when preparing forage using a plate: 1—distance from the plate to the nozzle is 140 mm, plate inclination angle is 30 degrees; 2—distance from the plate to the nozzle is 140 mm, plate inclination angle is 45 degrees; 3—distance from the plate to the nozzle is 140 mm, plate inclination angle is 90 degrees; 4—distance from the plate to the nozzle is 205 mm, plate inclination angle is 90 degrees; 5—distance from the plate to the nozzle is 305 mm, plate inclination angle is 90 degrees.

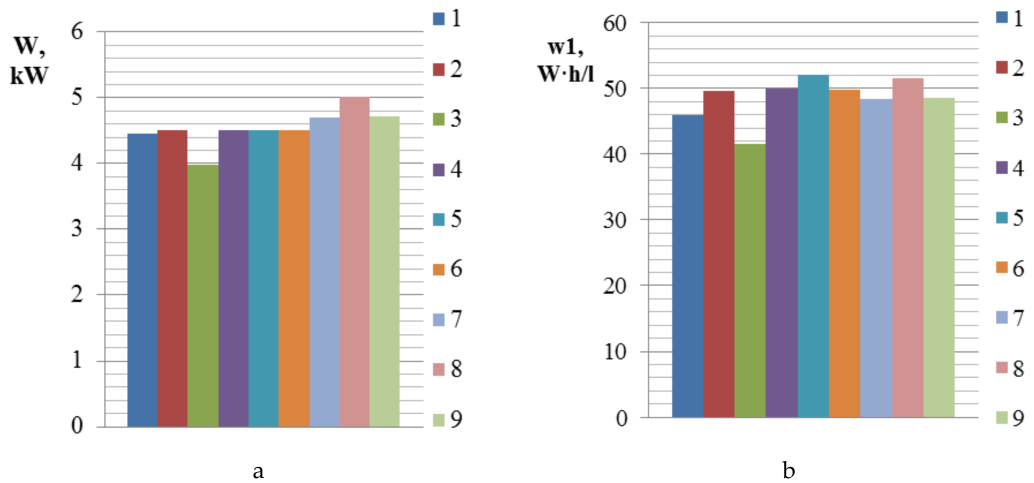

Figure 16. The influence of the studied parameters on: a—power consumption of the electric motor; b—specific energy consumption; 1—distance from the grid-work to the nozzle is 140 mm, grid-work inclination angle is 30 degrees; 2—distance from the grid-work to the nozzle is 140 mm, grid-work inclination angle is 45 degrees; 3—distance from the plate to the nozzle is 205 mm, grid-work inclination angle is 45 degrees; 4—distance from the grid-work to the nozzle is 205 mm, grid-work inclination angle is 30 degrees; 5—distance from the plate to the nozzle is 140 mm, plate inclination angle is 30 degrees; 6—distance from the plate to the nozzle is 140 mm, plate inclination angle is 45 degrees; 7—distance from the plate to the nozzle is 140 mm, plate inclination angle is 90 degrees; 8—distance from the plate to the nozzle is 205 mm, plate inclination angle is 90 degrees; 9—distance from the plate to the nozzle is 305 mm, plate inclination angle is 90 degrees.

4. Conclusions

As a result of studies of the working process of the developed patented plant for preparing forage from grain, and taking into account the aggregate estimate of the quality indicators of forage and the cost of electricity for its preparation, the optimal location parameters of the passive grinder have been found, allowing us to obtain high-quality forage with minimal power consumption of the electric motor. A grid-work should be used as a grinder. Its installation angle should be 30°, and the distance between the grid-work and the nozzle should be 205 mm. With this combination of parameters, the specific energy consumption is minimal and amounts to 41.5 W·h/L.

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References

1. Djuragic, O.; Levic, J.; Serdanovic, S.; Lević, L. Evaluation of homogeneity in feed by method of microtracers. *Arch. Zootech.* **2009**, *12*, 85–91.
2. Flizikowski, J.; Tomporowski, A. Movement characteristics of multi-disc cereal crusher. *Przemysł Chem.* **2013**, *92*, 498–503.
3. Flizikowski, J.; Sadkiewicz, J.; Tomporowski, A. Use characteristics of six-roll milling of grained raw materials for the chemical and food industry. *Przemysł Chem.* **2015**, *94*, 69–75.
4. Tomporowski, B.; Flizikowski, J.; Kruszelnicka, W. A new concept for a cylindrical plate mill. *Przemysł Chem.* **2017**, *96*, 1750–1755.
5. Svihus, B.; Kløvstad, K.H.; Perez, V.; Zimonja, O.; Sahlström, S.; Schüller, R.B.; Prestløkken, E. Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill. *Anim. Feed Sci. Technol.* **2004**, *117*, 281–293. [CrossRef]
6. Sysuyev, V.A.; Aleshkin, A.V.; Savinykh, P.A. Feed-processing machines. In *Theory, Development, Experiment*; North-Eastern Zonal Agricultural Research & Development Institute: Kirov, Russia, 2008; Volume 1.
7. Ali, E.; Morad, M.M.; Fouda, T.; Elmetwalli, A.; Derbala, A. Development of a local animal feed production line using programming control system. *MISR J. Agric. Eng.* **2016**, *33*, 181–194.
8. Bulgakov, V.; Pascuzzi, S.; Ivanovs, S.; Kaletnik, G.; Yanovich, V. Angular oscillation model to predict the performance of a vibratory ball mill for the fine grinding. *Biosyst. Eng.* **2018**, *171*, 155–164. [CrossRef]
9. Kusmierczak, S.; Majzner, T. Comprehensive approach to evaluation of degradation in chosen parts of energy equipment. *Eng. Rural Dev. Proc.* **2017**, *12*, 673–679.
10. Bulgakov, V.; Holovach, I.; Bandura, V.; Ivanovs, S. A theoretical research of the grain milling technological process for roller mills with two degrees of freedom. *INMATEH Agric. Eng.* **2017**, *52*, 99–106.
11. Savinykh, P.; Kazakov, V.; Czerniatiev, N.; Gerasimova, S.; Romanyuk, V.; Borek, K. Technology and equipment for obtaining starch syrup with ground and whole cereal grain. *Agric. Eng.* **2018**, *22*, 57–67. (In Russian)
12. Vaculik, P.; Maloun, J.; Chladek, L.; Poikryl, M. Disintegration process in disc crushers. *Res. Agric. Eng.* **2013**, *59*, 98–104. [CrossRef]
13. Yancey, N.; Wright, C.T.; Westover, T.L. Optimizing hammer mill performance through screen selection and hammer design. *Biofuels* **2013**, *4*, 85–94. [CrossRef]
14. Ghorbani, Z.; Masoumi, A.; Hemmat, A. Specific energy consumption for reducing the size of alfalfa chops using a hammer mill. *Biosyst. Eng.* **2010**, *105*, 34–40. [CrossRef]
15. Linke, B.S.; Dornfeld, D.A. Application of axiomatic design principles to identify more sustainable strategies for grinding. *J. Manuf. Syst.* **2012**, *31*, 412–419. [CrossRef]

16. Sysuev, V.; Savinyh, P.; Saitov, V.; Gałuszko, K.; Caban, J. Optimization of structural and technological parameters of a fermentor for feed heating. *Agric. Eng.* **2015**, *12*, 99. (In Russian)
17. Motovilov, K.; Motovilov, O.; Aksyonov, V. *Nanobiotechnology in the Production of Forage from Grain for Animal Husbandry: A Monograph*; Publishing House of the Novosibirsk State Agrarian University: Novosibirsk, Russia, 2015. (In Russian)
18. Donkova, N.; Donkov, S. Biotechnology for the production of sugars from grain raw materials. *Bull. Krasn. State Agrar. Univ.* **2014**, *6*, 211–213. (In Russian)
19. Volkov, V. Efficiency of up-to-date equipment for the production of forage from grain. *World Sci. Cult. Educ.* **2013**, *1*, 351–354. (In Russian)
20. Aksyonov, V. Up-dating the lines for obtaining feed forage from grain raw materials using cost-effectiveness analysis. *Bull. Krasn. State Agrar. Univ.* **2011**, *12*, 220–224. (In Russian)
21. Novosibirsk Prototype Manufacturer of Non-Standard Equipment-Selmash LLC. Available online: http://noezno.ru/equipment/korm/kip-06/kip-06 (accessed on 12 April 2019).
22. Agrotechnology. Available online: http://www.stav-agro.ru/index.php/katalog/urva-250.html (accessed on 15 May 2018).
23. Agrobase. Available online: https://www.agrobase.ru (accessed on 12 April 2019).
24. Short Feeding of Cattle. Available online: http://agrokorm.info/ru/kormoagregat-mriya-05/1/ (accessed on 12 April 2019).