Study of the process of heating water in the plant for the preparation of grain molasses

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Abstract. In the Russian Federation, grain molasses is gaining wide popularity when feeding farm animals. Developed technologies for its preparation include the process of heating water. Existing installations for the production of grain molasses conduct water heating in the pump due to cavitations. We proposed to use a passive chopper to speed up the process of preparing molasses and improve its quality. The article presents the description of the installation, methods of research and results of water heating in the installation. The influence of the following factors on the heating rate and power consumption was studied: distance from the nozzle to the grate, the angle of inclination of the grate. The assessment of the working process of the plant was carried out by the rate of water heating and the specific cost of electricity for its heating. As a result of research optimum parameters of the passive chopper at which heating occurs faster and with smaller expenses of the electric power are revealed. The studies of water heating in the plant for the preparation of grain molasses allow us to conclude about the possibility of intensification of the process and reducing energy costs for its implementation by changing the parameters of the grid installation. In this case, preference is given to the heating method with the use of an angled grille.

1. Introduction

In the world practice, when feeding farm animals mainly concentrate types of feeding are used [1, 2, 3, 4]. In the main processing of lead concentrates it is dialed with grain conditioners. Currently, in Russia, grain molasses is increasingly popular when feeding farm animals, especially dairy cows. This is primarily due to the fact that grain molasses contains a large amount of carbohydrates that have a positive impact on the productivity and health of animals [5]. Besides technologies of preparation of grain molasses in the conditions of the agricultural enterprises are developed [6, 7, 8, 9]. In turn, this allows you to reduce the cost of its preparation, always get fresh molasses, as well as use spoiled grain, which cannot be fed in the traditional form (crushed, flattened, etc.). During the preparation of molasses changes the viscosity of the medium, which depends on the type of pectin [10]. The technology of preparation of grain molasses involves heating the water to a certain temperature due to the process of cavitation, which takes place in the pump. We have proposed the design of the installation, which allows speeding up the process of cooking grain molasses. The article presents the results of the study of the process of water heating in the developed installation.
2. Materials and Methods

The study of the water heating process was carried out on a laboratory installation, the General view and scheme of which is presented in figure 1. The main elements of the installation are the tank 6, into which the components of the grain molasses (water, grain, enzymes) are loaded, the blade pump 9, driven by an electric motor 10, the system of material pipelines 8, designed to transport water and its mixture with grain. The pump drive is controlled from the control panel 1. The technology of preparation of grain molasses provides preheating of water in the installation to a temperature of 60 °C. The most common is its heating due to the effect of cavitation. In this case, the main heating of the liquid occurs in the pump chamber under the action of its impeller blades. Partially heating is due to water friction on the walls of the material pipelines. We put forward the assumption that the water heating can be accelerated to some extent by installing a chopper 5 (figure 1 b, c). In this case, additional heating will occur due to the impact of the water jet on the grid 12 (figure 1 c). The second function of the grate is grain grinding. Moving with the water and hitting the grid, it will further collapse. This will reduce the time for the preparation of molasses and improve its quality.

At the first stage of research, the influence of the water heating scheme in the installation was studied. Three heating schemes were studied. In the first scheme, water heating was carried out without insulation by a pump, the engine power of which was 5.5 kW. In the second scheme water heating at simultaneous work of the pump and a heating tape was studied (the heater was absent, power of a heating tape made 2.5 kW). According to the third scheme water heating was carried out at its joint heating by the pump and a heating tape, but thermal insulation of installation by a heater (penofol in the thickness of 10 mm) was carried out (figure 1).

When conducting experiments with heating tape used a specially designed device that allows you to evenly distribute the tape inside the tank of the installation, to carry out its rapid installation and dismantling (figure 2 a, b). Before installation, the device with the tape was folded (figure 2 c). It was placed in the tank through a hatch for loading feed components (figure 1 b). The device was then laid out inside the tank as shown in figure 2 b.
At the second stage, comparative studies were carried out to study the influence of the type of shredder on water heating. A grid with round holes and a solid plate were considered as a shredder (figure 3). Comparative studies were carried out at the same setting parameters $z$ and $\varphi$.

The third stage of research was aimed at determining the influence of nozzle diameters $2$ on the heating process (figure 1 b, c). In research, boundary conditions of the sizes of diameter of a hole of a nozzle were considered: 25 and 41 mm. A diameter of 41 mm corresponded to a diameter of a section of the pipeline, a diameter of 25 mm defined parameters of the confuser (figure 4 a, b).

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**Figure 2.** Device for mounting-dismantling and uniform distribution of the heating tape inside the tank

**Figure 3.** Investigated types of shredder: $a$-grid; $b$-plate

**Figure 4.** Nozzles: $a$-with a hole diameter of 25 mm; $b$-with a hole diameter of 41 mm
The final stage of the research was aimed at studying the influence of the gap $z$ and the angle $\phi$ on water heating (figure 1 c). During the experiment, the following combinations of parameters were set: $z = 205 \text{ mm}$, $\phi = 90^\circ$; $z = 205 \text{ mm}$, $\phi = 45^\circ$; $z = 205 \text{ mm}$, $\phi = 30^\circ$; $z = 140 \text{ mm}$, $\phi = 90^\circ$; $z = 140 \text{ mm}$, $\phi = 45^\circ$; $z = 140 \text{ mm}$, $\phi = 30^\circ$.

The experiment was carried out in the following sequence. In the tank 6 through the hatch 4 we poured 100 liters of water (figure 1 b). The volume of the filled water was recorded by the ICS 15-3-8 meter (figure 5, a). After filling the tank, the pump was turned on and the water temperature was fixed every 5 minutes. The temperature value was recorded from the digital display of the temperature controller TL-11-250, the data of which were transmitted from the temperature sensor TST81 (figure 5, b). At the same time with temperature fixing device Mastech MS2203 measurement of the power consumed by the electric motor was carried out (figure 5, c). The results of measurements were entered in the corresponding tables. According to the tables built graphs that show the change in water temperature from the time of operation of the installation. Also, on the basis of the results, diagrams are constructed that show the change in specific energy costs (figures 6-9).

![Figure 5](image)

Figure 5. Devices used in the experiment: a-water meter SVK 15-3-8; b-thermostat TL-11-250; c-Mastech MS2203

The specific cost of electricity for heating 1 liter of water at 1°C was calculated by the formula:

$$w_i = P \cdot \frac{\tau}{V \cdot \Delta T}, \quad (1)$$

where $P$ – average power consumption of the electric motor, kW;
$\tau$ – water heating time, s;
$V$ – tank water volume, l;
$\Delta T$ – the change in water temperature, ºC.

3. Results and discussion

When analyzing the results of the study of water heating schemes in the installation, graphs are constructed and equations of water temperature change from time are obtained (figure 6 a):

1 - $T = 0.4967 \cdot t + 21.407$;
2 - $T = 0.8 \cdot t + 20$;
3 - $T = 0.7934 \cdot t + 21.121$.

The equations describe the heating process quite accurately, as evidenced by the high values of the determination coefficients: the analysis of the graph showed that the use of a heating tape in conjunction with a pump as an additional heat source allows accelerating the heating process by more than 40% (figure 6 a).

The use of insulation does not give a significant result when accelerating heating (figure 6 a), but allows you to significantly reduce the specific energy consumption when heating water (figure 6 b). Specific energy consumption is reduced in this case from 1.81 to 1.14 kW·h / (l · ºC) (figure 6 b).
Figure 6. Changes in temperature and pressure (a) and unit cost of electricity (b) by heating 100 liters of water using a nozzle with a hole diameter of 25 mm ($\varphi = 90^\circ$, $z = 105$ mm): 1 – pump; 2 – a pump and a heating strip; 3 – pump, heating tape and insulation.

Thus, in order to reduce the specific cost of electricity can be recommended to heat the water using insulation. An additional heating element can be used to speed up the heating process.

When conducting a comparative experiment of water heating using a grid and a plate, the following was revealed. Water heating in the plant for option 4 is described quite accurately by the equation the use of the plate as a chopper allows one to accelerate the process of water heating by 10% (figure 7 a), but entails a sharp increase in the cost of electric energy from 1.8 to 2.8 kWh·(l·°C) (figure 7 b). That is, when water is heated in the developed installation, it is rational to use the grid as a chopper. Therefore, further studies of water heating were conducted with a grid.

Figure 7. Changing the temperature head (a) and specific energy consumption (b) when heating 100 liters of water using a nozzle with a hole diameter of 25 mm (at $\varphi = 90^\circ$, $z = 105$ mm): 1 - with a grid; 4 - with a plate

One of the main parameters affecting the operation of the plant for the preparation of grain molasses is the diameter of the nozzle d (figure 1 c). Studies have shown that water heating is faster with a larger nozzle diameter (figure 8 a). The reduction in heating time can reach from 11 to 32% depending on the distance z (figure 1 c). Increasing the diameter of the nozzle also reduces the energy consumption for heating from 1.8 to 1.62 kWh·(l·°C) (figure 8 b).
Figure 8. Change in temperature head (a) and specific energy consumption (b) when heating 100 liters of water using nozzle C: 1-d = 25 mm at φ = 90°, z = 105 mm; 5-d = 41 mm z = 205 mm, φ = 90°; 8-d = 41 mm, z = 140 mm, φ = 90°.

Next, we determined the influence on the heating of water such parameters as the distance z between the supply nozzle and grille, the angle φ of inclination of the lattice at a fixed value of nozzle diameter d = 41 mm. In result of analysis of the results obtained accurate equation describing the change in water temperature from the heating time:

5: \( T = 0.5544 \cdot t + 21.522, R^2 = 0.9991; \)
6: \( T = 0.7161 \cdot t + 21.141, R^2 = 0.9995; \)
7: \( T = 0.6495 \cdot t + 21.093, R^2 = 0.9975; \)
8: \( T = 0.7161 \cdot t + 21.141, R^2 = 0.9995; \)
9: \( T = 0.6721 \cdot t + 21.393, R^2 = 0.9988. \)

Figure 9. Effect of the distance z between the nozzle and the grate and the angle φ of the grate installation on the intensity of water heating (a) and specific energy consumption (b): 5-z = 205 mm, φ = 90°; 6-z = 205 mm, φ = 45°; 7-z = 205 mm, φ = 30°; 8-z = 140 mm, φ = 90°; 9-z = 140 mm, φ = 45°; 10-z = 140 mm, φ = 30°.
In general, the heating of water flows faster when installing the grid at a distance of \( z = 140 \) mm. The best options are 6, 8 and 9 (figure 9a).

Specific energy costs vary from 1.51 to 1.71 kW·h / (l · °C) depending on the combination of parameters \( z \) and \( \varphi \) (figure 9b). On the basis of a joint analysis of the graphs of temperature changes (figure 9a) and diagrams of changes in specific energy consumption (figure 9b), it can be recommended to install the grid at an angle.

4. Conclusion

Thus, the studies of water heating in the plant for the preparation of grain molasses allow us to conclude about the possibility of intensification of the process and reducing energy costs for its implementation by changing the parameters of the grid installation. In this case, preference is given to the heating method with the use of an angled grille.

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