Method of engineering calculation of recuperator parameters for heat extraction from tempered soybeans

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Abstract. In the conditions of constant growth of prices for consumed energy and competition in the domestic market, rural commodity producers have a problem to reduce energy costs, since they make up a significant share in the cost of agricultural products. There are particularly high energy costs in the heat treatment of meat and dairy products and grain. To reduce energy costs for thermal purposes, you can use the secondary heat extraction and its use in a specific technological process. To calculate the parameters of a heat recuperator that reuses heat energy from heat-treated soybeans, an engineering calculation method is presented.

1. Introduction

It is well known that the traditional methods of producing animal protein in feed have already exhausted themselves, there is a need to replenish protein in feed in a simpler and cheaper way, and if possible to produce additives directly on your own farm. Many studies have proved that one of the ways to solve this problem is to replace animal proteins, which are currently used in animal husbandry as an additive in feed, with a protein of plant origin. Scientists have found that soy is the most suitable substitute for animal protein. Soy grain contains 30-45% protein, up to 20% fat, as well as vitamins A, B, C, D, E, PP. According to these indicators, soy protein is close to animal proteins [1]. However, soy grain should not be fed to animals without pretreatment, as its consumption by animals can be dangerous. This is mainly due to the content of trypsin, allergens, urease, and etc. in soy grains. In the animal body, they block digestive enzymes and thus reduce the digestibility of proteins, as well as cause pancreatic hypertrophy and growth retardation of animals [2].

The conducted information and patent studies have shown that for removal of anti-nutritive substances the best efficiency is provided by heat treatment of grain by means of various methods of heat production. Also, many authors note the need not only to heat the grain to a certain temperature, but also to keep it at this temperature for a certain time. In addition, it is also necessary to maintain a certain humidity before starting the heat treatment of soybeans. The parameters that significantly affect the course of the technological process are the temperature and duration of heat treatment of soybean grain [2].

To date, scientists have developed many methods and technological techniques for removing harmful substances from soy grain: roasting, micronization, extrusion, microwave processing,
autoclaving, germination and dispersion. The main technical means that determines the effectiveness of the removal of anti-nutrient substances are different in principle of operation and design of the device for heating and maintaining a given temperature regime in the high-temperature working chamber and in the temperator. Their main disadvantages are the complexity of the technological process of processing soybeans, high-cost and energy-intensive, low productivity and high labor costs [3-5].

The results of information and patent studies indicated the need to develop a new method of processing soybeans and to create a promising technical means with an energy supply system that allows for two-way heating of soybeans and, as a result, to redistribute heat flows and increase the uniformity of heating by grain volume, the quality of processing, the productivity of the plant and reduce the specific energy costs [2, 5, 6]. However, heat treatment with the new method is also energy-consuming.

It is well known that in many sectors of the national economy of Russia and abroad, where technology allows, heat recovery is used for its secondary use in various technological processes. There are an infinite number of ways and technical means of secondary heat extraction [1, 2, 7, 8]. Note only that each method and design of the device takes into account the features of the technological process and it is impossible to apply them to a specific technological installation for the heat treatment of soybeans.

The purpose of the work is to develop a method of engineering calculation of the parameters of a heat recuperator with a heat exchange plate located in the temperator

2. Materials and methods
The methods of system analysis and synthesis of existing knowledge in the field of ongoing studies on the use of heat recuperator are applied.

3. Results and Discussion
Since the heat treatment of soybeans is carried out at a high temperature (120 – 135 °C), additional energy savings can be provided by extracting heat from it in a temperator: in a special heat-insulating hopper with a heat recuperator. However, for the design of the heat recuperator, the engineering calculation method is necessary.

A specific example of the secondary use of heat from tempered soybeans is the heating of water at the humidification stage, since in the technology of heat treatment of soybeans, the humidification of soybeans is mandatory. At a water temperature of 10...20 °C, humidification lasts, depending on the soybean variety and the initial humidity, from 1 to 5 hours. Studies have shown that it is possible to reduce the humidification time by 3...5 or more times if you moisten it with heated water up to 60 ... 80 °C. Since the soybean sludge in the temperator (a special heat-insulated hopper) lasts 15 minutes, the water can be heated to moisten it from hot soy, which transfers heat to the water through the walls of the recuperator. The result is a double effect: saving energy and reducing the time of humidification of soy.

Taking into account the design of the temperator, it is advisable to use a recuperator with a heat exchange plate (figure 1) installed in the lower part of the temperator (figure 2).
Cold water connection

Heated water connection

**Figure 1.** Heat exchange plate for heat recuperator

Cold water is fed into the plate cavity, due to the transfer of heat in the temperator from hot beans and partly from the steam of heated and moistened soybeans through the wall of the heat exchanger, the water is heated.

**Figure 2.** The design diagram of the temperator (1) with the soi (2) placed in it and the heat exchange plate (3) of the heat recuperator.

Experimental studies have shown that the humidity of heat-treated soybeans should be at the level of 20%. Let's determine the water requirement for moistening the beans. Let's assume the initial moisture content of the beans is 10% (from the storage warehouse). Then, to moisten up to 20%, the weight of the beans of equal productivity (240 kg/h) will need 24 kg/h. To heat this amount of water from 10 to 80°C will require heat

\[ Q_v = 1.16 \times 10^{-3} \cdot c \cdot m \cdot (t_k - t_n) = 1.95 \text{ kW} \cdot \text{h} \]  

(1)

It is experimentally established that the cycle of tempering (settling time) of grain should be 15 minutes (1/4 hour). Therefore, during this time, 60 kg of heat must be treated in the temperator and the capacity of the temperator must not be less than this value.

\[ M_t = 240/4 = 60 \text{ kg} \]  

(2)

During the same time, it is necessary to make a extraction of heat in the temperator, the value of which is
\[ Q_{\text{uvl}} = \frac{Q_{\text{uvl}}}{4} = 0.488 \text{ kW} \cdot \text{h} \]  

To extract this heat from the grain of the heated soybean, it is necessary to determine the parameters of the heat exchange device - the heat recuperator.

The heat flow through the heat exchanger wall is determined by

\[ Q = k \cdot F_t \cdot (t_1 - t_2) \]  

where \( Q \) is the heat flow coming through the heat exchanger wall, W;
\( F_t \) is the heat transfer surface of the heat exchanger, m\(^2\);
\( t_1 \) is the temperature of the steam-air mixture and the heated soy in contact, °C;
\( t_2 \) is the temperature of the water supplied to the heat exchanger, °C.

The heat transfer coefficient \( K \) is determined by analogy as in a shadowless heat source (SHS), in which heat from a vapor-air mixture is transferred from one side of the heat transfer wall, and water is heated from the other side of this wall

\[ K = \frac{q_{\text{bit}}}{F_{\text{bit}} (t_p - t_b)} \]  

where \( q_{\text{bit}} \) is the heat flow of SHS, kW (according to previously conducted experimental studies, \( q_{\text{bit}} = 4 \text{ kW} \));
\( F_{\text{bit}} \) is the heat transfer surface of the SHS equal to 0.4 m\(^2\);
\( t_p, t_b \) – the temperature of the steam-air mixture and the heated water (\( t_p = 100 \text{ °C} \), \( t_b = 10 \text{ °C} \)).

Determine the heat transfer surface of the heat exchanger required to transfer the water used to moisten the soybean to heat. With the capacity of the unit \( m_u = 240 \text{ kg/h} \), the heat transferred from the heat exchanger in 1 hour is \( Q = 1.95 \text{ kWh} \), for a tempering cycle of 15 minutes \( Q_{ct} = \frac{1.95}{4} = 0.488 \text{ kWh} \).

With a known heat transfer coefficient, the formula for determining the heat transfer surface has the form

\[ F_t = \frac{q_t}{K (t_{av} - t_u)} \]  

where \( t_{av} \) is the average temperature of the soybean in contact with the heat exchanger (the soybean is cooled from the cold wall of the heat exchanger).

It should be noted that the heat exchanger should be placed in the remaining pyramidal part of the temperator below the mass of soy, tempered for 15 minutes. This condition must be met to prevent the temperature of the soybean from decreasing at the top of the temperator.

Based on the size of the lower part of the temperator, the dimensions of the heat exchange plate are accepted: height-0.3 m, length-0.5 m. Then the heat transfer surface is equal to

\[ F_t = 0.3 \cdot 0.5 \cdot 2 = 0.3 \text{ m}^2 \]  

The experimental sample of the heat exchanger is made with these dimensions.

It should be noted that the heat transfer coefficient is determined for specific parameters of the heat exchanger walls: material is stainless steel, 1 mm thick; specific thermal conductivity, \( \lambda \) W/(m·°C).

And in order to develop a calculation method and calculate the parameters of the heat exchanger with other wall materials (copper, aluminum, etc.), and with other geometric parameters, it is necessary to determine the heat transfer coefficient from the steam – air mixture and the contacted soy to the wall of the recuperator - \( \alpha_1 \), located in the temperator.

For a known heat transfer coefficient \( k \), the value \( \alpha_1 \) can be determined from the equation:
\[ k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}}, \]  

where \( \delta \) is the wall thickness, m; 
\( \lambda \) is the specific thermal conductivity of the wall, W/(m·°C); 
\( \alpha_2 \) is the coefficient of heat transfer from the inner wall of the recuperator to the heated water, W/(m·°C) – this coefficient is available in the reference literature.

Transform (8)

The known values are denoted by: 
\[ \left( \frac{\delta}{\lambda} + \frac{1}{\alpha_2} \right) = A \]

Then

\[ \alpha_1 = \frac{k}{1 - k \cdot A} \]  

Taking into account the heat transfer coefficient from the steam-air mixture and from the contacting hot soy to the recuperator wall, it is possible to calculate the parameters of the heat recuperator with other materials of the heat exchanger walls and with its other geometric parameters.

4. Conclusion

The developed method of engineering calculation allows us to determine the parameters of the recuperator for the extraction of heat from the tempered soybean.

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