Parameters of the heat-generating installation on biofuel for grain drying

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Abstract. According to forecasts of leading analytical agencies, in the near future about 50% of all bioenergy will be received from the biomass of the agro-industrial complex. The main factors stimulating the use of waste from the production and processing of crop products are: renewable resources; lower unit cost of energy production; reduction of harmful effects on the environment and humans. An analysis of the structure of the resource potential of grain waste in terms of their origin showed that the largest share in the Tyumen region of Russia, more than 50%, consists of spring and winter wheat waste. The article presents the results of a study of the operation of a heat-generating installation on various cereal wastes as applied to the grain drying process. The rational parameters of the heat generator for the waste of wheat, oats, barley and rapeseed are determined: biofuel consumption, air supply to the heat generator and mixing chamber; the temperature of the drying agent at the exit of the heat generation section. The solid-fuel vortex heat generator is 2 MW power. The mass of the batch of waste from each enterprise ranged from 600 to 1000 kg. In order to ensure the movement of the mixture of combustion products and air in the axial direction to the mixing chamber, the ratio of the rotational speeds of the blower fans should be \( n_1/n_2 = 1.3 \). The temperature of the agent at the outlet of the furnace during the combustion of all waste samples was within 755-830 °C. Fuel consumption for a heat generator during the combustion of rapeseed and wheat waste is 450.4 kg/hour. The optimal moisture content of biofuel for combustion in vortex furnaces is 10-20%.

1. Introduction

In world practice, energy production based on alternative sources is increasing. The main factors stimulating the use of waste from the production and processing of crop products are: renewable resources; lower unit cost of energy production; reduction of harmful effects on the environment and humans.

According to the Department of agro-industrial complex of the Tyumen region, agricultural enterprises have significant potential in terms of the availability of grain waste, the total amount of such waste is on average about 140 thousand tons per year. The output of grain waste during refinement at enterprises is 5-13% of the bunker weight.

The growth trend in the use of bioenergy in world and Russian practice is confirmed by forecasts of leading analytical agencies, and according to Fachagentur Nachwachsende Rohstoffe (FNR) [1], 50% will be the share of bioenergy obtained from biomass of the agro-industrial complex.
An analysis of the structure of the resource potential of grain waste in terms of their origin showed that the largest share in the Tyumen region, more than 50%, are waste from spring and winter wheat. The share of barley waste is 19.11%, oats and rapeseed - 16.52% and 7.43%, respectively (Figure 1).

![Figure 1. The structure of grain waste in the Tyumen region, depending on the type of crop.](image)

Currently, according to the Department of Agriculture, more than 100 items of various types of domestic and foreign grain dryers are operated in the grain drying park of the Tyumen Region: USA - FARM FANS, QED, MEYER, DELUX, Mini-Max, Mathews, Cukup, Neco; Germany - PETKUS, NEUERO, Schmidt-Seege, MONSUM LACHENMEIER, RIELA; Denmark - CIMBRIA, CROCUS; Sweden - TORNUM; Finland - ANTTI, MEPU; Poland - ARAJ, AG - PROJEKT; Italy - AGREX, MECMAR, PEDROTTI; Ukraine - DSP-10/20/25; DSP-50 and others, as well as grain dryers of domestic producers: Bryansksemlash JSC, Voronezhsemlash JSC, Melinvest JSC, Agropromtehnika CJSC, Tverselmash CJSC, Sibirskiy Agropromyshlenny Dom CJSC. More widely represented in the Tyumen region are domestic manufacturers of grain drying equipment, their share is 64.3%. Almost equally represented are manufacturers of grain dryers from Germany and the USA, 9.2% and 8.2%, respectively [2, 3] (Figure 2).

The total number of dryers in operation in the farms of the south of the Tyumen region is more than 370 pcs. The following models are the most common: M 819, SZ-10.16, Vesta-20.30, MS-1175, Araj S614, DSP-32, SZSB-8, SZSh-16, Araj S69, Perry M214, DSP-50, ALVAN BLACH DF 17655.

Most grain dryers are stationary and shaft type, but a number of farms use mobile grain dryers such as MECMAR, PEDROTTI, ATM [4, 5].

![Figure 2. Countries producing grain drying equipment used on farms in the Tyumen region.](image)
The analysis of grain drying equipment used in the field shows that the majority are stationary dryers of the mine type, the type of fuel used is natural gas.

2. Materials and Methods
The aim of the study is to determine the rational parameters of the heat generator working on grain waste (biofuel), taking into account the specifics of their origin.

Place of the experiment: production base of the enterprise “Zavodoukovsky maslozavod” LLC, Zavodoukovsk, Russia.

The studied parameters: biofuel consumption, air supply to the heat generator and mixing chamber; the temperature of the drying agent at the exit of the heat generation section.

2.1. Equipment and materials
The plot of preparation of the heat carrying agent for the dryer (Figure 3):

A solid fuel heat generator with a capacity of 2 MW, its purpose is to prepare a heat carrying agent for the drying of biomass (plant materials) due to the highly efficient burning of low-grade solid fuel. Plant productivity is 563 kg/h. The unit is connected to a grain drying complex.

Structurally, the heat generator is a double-walled steel cylinder. The inner cylinder has blast holes in its surface and is lined with high-temperature fireclay bricks, part of which has special blast nozzles made of a material that can withstand temperatures of 1650 °C. Blower air is pumped by fans into the cavity between the cylinders, where it is heated, while cooling the inner cylinder, and then through the blower nozzles it enters the pyrolysis or afterburning zone. Since the blast nozzles are located tangentially both in the pyrolysis zone and in the afterburning zone, the air flow creates a vortex, causing fuel particles to move along the longest path and cling to the hot surface of the lining, which causes them to burn out almost completely. Blast air for ignition and fuel is also supplied tangentially and is heated.

Figure 3. Plot of heat generation from grain waste of “Zavodoukovsky maslozavod” LLC (Russia).

Power equipment of the heat generator:
1. Motor-reducer of a tedder of an operational bunker RS-110 (Nst = 1.1 kW - stated power of a motor-
reducer, rotation speed - 9 rpm.)
2. Motor reducer of the auger conveyor of the operational hopper RS-100 (Nst = 1.1 kW - stated electric motor power, rotation speed - 9 rpm.)
3. Draft-blowing machine DN-6.3 of fire chamber - 2 pieces (Nst = 4.0 kW - stated electric motor power, rotation speed - 1000 rpm.)
4. Draft-blowing machine DN-8 of the mixing chamber - 1 piece (Nst = 11.0 kW - stated electric motor power, rotation speed - 1000 rpm.)
5. Motor-reducer of auger conveyor for ash removal from the RS-90 furnace (Nst = 0.55 kW - stated electric motor power, rotation speed - 9 rpm).

Six test batches of grain waste from Russian enterprises of the Tyumen region were used for the study (“Plemzavod-Yubileiny” CJSC, “Agrofirma KRiMM” LLC, “Zavodoukovsky elevator” LLC, “UNIGREIN” LLC, “Ishimskiy kombinat khleboproduktov” LLC). The mass of the batch of waste from each enterprise ranged from 600 to 1000 kg.

2.2. The procedure of the experiment
1. Each batch of samples was burned separately. The complete combustion cycle consisted of loading a batch of waste into the fuel depot, completely burning the batch of waste, and adjusting and fixing the parameters. Before each next type of fuel was used, “the living floor” devices and operational hopper were cleaned of the previous fuel.
2. Humidity of all kinds of prototypes was defined in the laboratory of the enterprise prior to the process of burning by standard methods.
3. The parameters of the heat generator were monitored on a standard control panel, which allows you to record the values of the biofuel consumption rate, air supply to the heat generator and the mixing chamber; the temperature of the drying agent at the exit of the heat generation section.

The Figure 4 presents the principle diagram of the heat carrying agent preparation.

Figure 4. Principle diagram of the preparation of the heat carrying agent.

Where: 1. Automatic fuel depot; 2. The conveyor from the fuel depot to the drying-grinding unit; 3. Operational bunker of a heat generator with fuel level sensors; 4. The conveyor of the operational hopper into the fire chamber of the heat generator; 5. Fire chamber of the heat generator; 6. Fan No. 1 of the fire chamber; 7. Fan No. 2 of the fire chamber; 8. The mixing chamber of the heat generator; 9. The fan for supplying air to the mixing chamber; 10. Emergency-kindling pipe with automatic shutter of the heat generator; 11. Gas flue from the mixing chamber to the exhaust fan; 12. Automatic spark detection and suppression system; 13. The smoke exhauster of the heat generator; 14. The gas flue from the exhaust fan to the dryer; 15. Fire chamber temperature sensor; 16. The temperature sensor of the mixing
chamber; 17. The temperature sensor of the entrance to the drying unit; 18. Thermostat fire extinguishing system in the conveyor of operational hopper of fire extinguishing system; 19. Ash disposal system; 20. Ash container; 21. Control cabinet of the heat generator; 22. Fuel level sensors; 23. The reloader. 24. The unit for drying and grinding of biofuel. 25. Conveyor from the drying-grinding unit to the operational bunker of the heat generator.

Fuel from the fuel depot 1 is supplied by the conveyor 2 to the unit for drying and grinding of biofuel 24. The crushed fuel with the necessary moisture is supplied into the operational hopper 3. Next, the fuel is supplied by conveyor 4 to the heat generator 5 in premeasured amounts.

Structurally, the heat generator is a double-walled steel cylinder. The inner cylinder has blast holes in its surface and is lined with high-temperature fireclay bricks, part of which has special blast nozzles. Blower air is pumped by fans into the cavity between the cylinders, where it is heated, while cooling the inner cylinder, and then through the blower nozzles it enters the pyrolysis or afterburning zone. Since the blast nozzles are located tangentially both in the pyrolysis zone and in the afterburning zone, the air flow creates a vortex, causing fuel particles to move along the longest path and cling to the hot surface of the lining, which causes them to burn out almost completely. Blast air for ignition and fuel is also supplied tangentially and is heated.

The combustion products through the flue are fed into the mixing chamber 8. In the mixing chamber 8, the fan 9 supplies air from the outside. In the mixing chamber 8, the combustion products and air are mixed and the temperature of the mixture reaches a predetermined level, but not more than 130 °C. Further, the combustion products through the flue 11 are fed to a smoke exhauster 13, which passes flue gases from the furnace of the heat generator 5 and supplies a mixture of combustion products and air into the flue 14. Then the heat carrying agent is supplied into the drying chamber through the gas flue 14. Emergency-kindling pipe with automatic shutter serves for kindling of the heat generator 5 and to switch to the kindling mode in case of emergency situation at the drying complex.

During operation of the fire chamber, the control system displays the temperature of the fire chamber by a predetermined value (readings of the temperature sensor pos. 15) and supports it by supplying fuel to the fire chamber with a conveyor pos. four.

The fan of the mixing chamber pos. 9 runs continuously in a nominal mode.

During operation of the heat generator, the control system displays the temperature of the heat carrying agent at the inlet to the drying unit by a predetermined value (readings of the temperature sensor pos. 17) and supports it by adjusting the position of the automatic shutter of the emergency-kindling pipe (pos. 10).

Automatic spark detection and suppression system 12 serves to detect and extinguish automatically sparks in the heat carrying agent before feeding it to the smoke exhauster.

When sparks are detected in the gas flue, the spark-signal sensor transmits a signal to the water supply device to the automatic spark suppression device.

Spark-signal sensors are mounted on the walls of the pipeline and detect sparks and smoldering, including dark, emitting only thermal radiation, particles immediately after they appear in the pneumatic transport system or on open conveyors. After detection and analysis immediately (the clean time from the moment of fixing the spark or hot particle to the issuance of the control command is 8 ms, the opening time of the nozzle is 250-300 ms. from the moment of detecting the spark or hot particle) countermeasures are introduced to eliminate the cause of the fire, pops or explosion.

A signal from the remote control panel starts a rapid automatic extinguishing system. It consists of a special solenoid valve having a high-speed opening characteristic of one or more nozzles. Installation of automation is carried out depending on the speed of transportation, approximately at a distance of 4 m behind the spark sensor. At the same time, the production process can continue unhindered.

3. Results and Discussion
To determine the rational operation parameters of a heat generator operating on grain waste when used on grain drying complexes [6–9], it is necessary to solve the following problems during the heat engineering calculation:
1. To determine a fuel consumption during operation of the heat generator in nominal mode.
2. To determine an air consumption, necessary to reduce the temperature of the combustion products to a predetermined temperature of the heat carrying agent of the drying unit.
3. To determine the heat carrying agent consumption of the drying unit during operation of the heat generator in the nominal mode.

To determine the power of the fire chamber, we use the formula:

\[ N_{fc} = \frac{N_{hg}}{\eta_{mix.cham}}, \text{ kW} \]  \hspace{1cm} (1)

where \( N_{hg} \) – heat generator required power, kW;
\( \eta_{mix.cham} \) – coefficient of efficiency of the mixing chamber.

Fuel consumption is determined from the formula:

\[ B_{hc} = \frac{3600 N_{hc}}{b_n \eta_{hc}}, \text{ kg} / \text{h} \]  \hspace{1cm} (2)

where \( \eta_{hc} \) – coefficient of efficiency of the heating chamber;
\( b_n \) – fuel NCV.

We determine the air flow consumption necessary to reduce the temperature of the combustion products to a predetermined temperature of the heat carrying agent of the drying unit.

Material balance of the mixing chamber:

\[ M_{mix} = M_{..} + M_{mix}, \text{ kg} / \text{h} \]  \hspace{1cm} (3)

The mass air flow supplied to the mixing chamber to reduce the temperature of the combustion products to the temperature of the heat carrying agent of the drying unit is determined from the formula:

\[ M_{air} = \frac{\eta_{mix.cham} C_{comb.pr} T_{comb.pr} - C_{mix} T_{mix}}{C_{mix} T_{mix} - \eta_{mix.cham} C_{air} T_{air}}, \text{ kg} / \text{h} \]  \hspace{1cm} (4)

\( M_{air} \) – mass air flow supplied to the mixing chamber to reduce the temperature of the combustion products to the temperature of the heat carrying agent of the drying unit, kg / h
\( M_{comb.pr} \) – mass flow of combustion products at temperature \( T_{comb.} = 900^\circ \text{C} \), kg / h;
\( \rho_{comb.pr} \) – heat carrying agent density under normal conditions, kg / m\(^3\);
\( \rho_{comb.pr.oper.} \) – density of combustion products at a temperature in the furnace, kg / m\(^3\);
\( V_{comb.pr} \) – volumetric flow rate of combustion products at temperature \( T_{r} = 900^\circ \text{C} \), m\(^3\) / h;
\( C_{comb.pr} \) – specific heat capacity of combustion products, kJ / (kg · K);
\( C_{mix} \) – specific heat capacity of combustion products and air mixture at temperature of 130\(^\circ\)C, kJ / (kg · K);

The density of the mixture of products of combustion of air at temperature of 130 °C is determined by the formula:

\[ \rho_{mix} = \frac{M_{comb.pr} \rho_{comb.pr} + M_{air} \rho_{air}}{M_{mix}}, \text{ kg} / \text{m}^3 \]  \hspace{1cm} (5)

where \( \rho_{comb.pr} \) – density of combustion products at temperature of 130 °C, kg / m\(^3\);
\( \rho_{air} \) – air density at temperature of 130 °C, kg / m\(^3\).

The volumetric flow rate of a mixture of combustion products and air can be determined by the formula:

\[ V_{mix} = \frac{M_{mix}}{\rho_{mix}}, \text{ m}^3 \]  \hspace{1cm} (6)

We consider an example of calculating a heat generator on grain waste with the required output thermal power of 2000 kW. The initial data for the calculation are presented in table 1.
Table 1. Initial data for calculating the heat generator when working on rapeseed waste.

| Fuel type              | Rapeseed waste         |
|------------------------|------------------------|
| Fuel humidity          | 30.00 %                |
| The proportion of water in fuel (W) | 0.30                  |
| Minimum ambient temperature | -5.00 °C              |
| Maximum ambient temperature | 30.00 °C              |
| Estimated fuel temperature | 0.00 °C               |
| The required power at the outlet of the heat generator | N_{hg} 2000.00 kw    |
| Heat carrier agent temperature | T_{hc} 1173 K          |
| The temperature of the mixture of flue gases and air at the outlet of the mixing chamber of the heat generator | T_{mix1} 300 °C |
| The temperature of the mixture of flue gases and air behind the emergency-kindling pipe of the heat generator | T_{mix2} 130 °C |
| η_{hc}                 | 0.97                   |
| η_{mix cham}           | 0.95                   |
| C_{hc}                 | 2.552 kJ / kg * K     |
| C_{air}                | 1 kJ / kg * K         |
| θ_{hc}                 | 278 K                  |
| T_{a,t} minimal        | 268.00 K               |
| ρ_{air}                | 1.31 kg/m$^3$         |

According to the fuel research data, it contains 9.59% ash on an absolutely dry mass. By conversion to the working mass at a fuel moisture content of 30%, we obtain the ash content of 6.71%. According to the heat engineering calculation, the fuel consumption will be 563 kg/h. Therefore, ash consumption will be - 38 kg/h. The average bulk density of ash is 600 kg/m$^3$. For a day it will be - 1.52 m$^3$/day or 912 kg/day.

Using the above method, the values of the parameters of the heat generators for working with the most common models of grain drying systems used in the Tyumen region are determined. In the calculations, it was assumed that the ambient temperature is 5°C.

In order to determine the parameters of biofuel consumption (rapeseed waste), the mass flow rate of air supplied to the mixing chamber, the amount of ash generated during the operation of the heat generator, the heat capacity of the grain dryer in the range from 0.5 to 10 MW was plotted in Figure 5-7.

![Figure 5](image)

**Figure 5.** Dependence of biofuel consumption on the thermal power of a grain dryer (fuel type - rapeseed waste, air temperature - 10 °C).
Figure 6. The dependence of the mass air flow, supplied to the mixing chamber to reduce the combustion temperature to the heat carrying agent temperature of the drying unit, from the heat capacity of the dryer (type of fuel - rapeseed waste air temperature - 10 °C).

Figure 7. Dependence of the amount of ash formed during the operation of the heat generator from the thermal power of the grain dryer (fuel type - rapeseed waste, air temperature - 10 °C).

Based on the results of the data obtained, indicators of the biofuel combustion process were evaluated and the modes of operation of the heat generator for each of the tested prototypes were selected.

The indicators of the heat generator operation are shown in table 2.
Table 2. The results of the heat generator operation on different samples of biofuel.

| Experiment number | Indication of the frequency converter DN-6.3 | Indicators of the frequency converter of fuel supply auger | Heat generator fan damper is open | Fire chamber outlet temperature | Note on the operation of the heat generator |
|-------------------|---------------------------------------------|----------------------------------------------------------|----------------------------------|---------------------------------|---------------------------------------------|
| No. 1             |                                             |                                                          |                                  |                                 |                                             |
| 1                 | 45 35                                       | 40                                                       | 5 5                              | 820 750                         | norm                                        |
| 2                 | 45 35                                       | 41.8                                                     | 5 5                              | 829 760                         | norm                                        |
| 3                 | 45 35                                       | 46.6                                                     | 5 5                              | 830 777                         | norm                                        |
| 4                 | 45 35                                       | 46.6                                                     | 5 5                              | 811 800                         | norm                                        |
| 5                 | 45 35                                       | 5                                                        | 5 5                              | 811 797                         | does not work                               |
| 6                 | 45 35                                       | 40                                                       | 5 5                              | 820 750                         | norm                                        |
| 7                 | 45 35                                       | 40                                                       | 5 5                              | 820 750                         | norm                                        |

As a result of the analysis of the results, taking into account the characteristics of the power equipment, the rational parameters of the heat generator were obtained (Table 3) for various types of grain wastes: wheat, barley, oats and rape.
Table 3. The results of the heat generator operation on different samples of biofuel.

| Experiment number | Fan rotation speed DN-6.3, rpm | Fuel consumption, kg / h | Fans air flow rate DN-6.3, m³ / h | The temperature of the agent at the outlet of the fire chamber, °C |
|-------------------|-------------------------------|--------------------------|-----------------------------------|---------------------------------------------------------------|
| No. 1              | No. 2                         | No. 1                    | No. 1 Upper limit                 | Lower limit                                                  |
| 1                  | 900                           | 700                      | 450.4                             | 5670 4410 830 755                                           |
| 2                  | Oats peelings W=13-14 %, "UNIGREIN" LLC | 900                           | 700                      | 469.1 5670 4410 817                                         |
| 3                  | Barley waste, W=15 %, “Zavodoukovsky elevator” LLC | 900                           | 700                      | 525.4 5670 4410 829                                         |
| 4                  | Wheat waste W=11-12 % “Ishimskiy kombinat khleboproduktov” LLC | 900                           | 700                      | 450.4 5670 4410 830                                         |
| 5                  | Wheat waste W=12-13 %, "Plemzavod-Yubileiny" CJSC | 900                           | 700                      | 450.4 5670 4410 830                                         |

4. Conclusions
1. As a result of thermal calculation, the technical parameters of the heat generators for various types of grain dryers used in the farms of the Tyumen region are determined. This technique is applicable to all types of grain drying complexes operating in the regions of Russia and abroad.
2. The rational operating modes of the heat generator for the waste of wheat, oats, barley and rapeseed are determined. To ensure the movement of the mixture of combustion products and air in the axial direction, to the mixing chamber, the ratio of the rotational speeds of the blower fans should be \( n_1 / n_2 = 1.3 \). The temperature of the agent at the outlet of the furnace during the combustion of all waste samples is within 755-830°C. The fuel consumption for a vortex heat generator during the combustion of waste rapeseed, wheat is 450.4 kg / hour.
3. Biofuel in the form of oat waste is suitable for use in vortex heat generators with an increase in consumption by 5%; fuel in the form of barley waste is suitable with an increase in fuel consumption by 15%; fuel in the form of rapeseed waste with a moisture content of more than 30% does not burn in the heat generator. An attempt to mix with dry oat waste in a ratio of 1: 1 also does not give any positive result.
4. The optimal moisture content of biofuels for combustion in vortex furnaces is 10-20%.

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