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RESEARCH OF THE OPERATION EFFICIENCY OF VEGETABLE BIOMASS-OPERATED SOLID FUEL BOILER

Об'єктом дослідження слугує процес забезпечення рівномірного розподілу палива по поверхні горіння топкової камери твердопаливного котла, що працює на біомасі. Рівномірний розподіл палива по поверхні горіння є одним з важливих важелів усунення явищ його хімічного та механічного недоспалювання, що підвищує ефективність роботи котельного обладнання. Однією з проблем дослідження даного питання є відсутність достатньої теоретичної бази і практичного досвіду щодо процесу хіміко-термічної конверсії рослинної біомаси в інші види енергії.

Запропоновано підхід, в основу якого покладена гіпотеза про можливість підвищити ефективність роботи котельного обладнання на рослинній біомасі шляхом встановлення інтенсивного і якісного процесу горіння, забезпечивши рівномірний розподіл палива по поверхні горіння. А також виявити закономірності та зазначити методи оптимізації структури конструкцій котельного обладнання шляхом його адаптації до рослинної сировини. Реалізація такого підходу здійснювалася шляхом проведення багатофакторного експерименту. Під час експерименту визначалася залежність коефіцієнту нерівномірності розподілу палива по площині горіння від висоти розташування сопла навантажувача, кута нахилу регулювальної плити навантажувача до поверхні дзеркала горіння і масової подачі палива.

В результаті дослідження отримано практичні результати, представлено математичні залежності коефіцієнту нерівномірності розподілу палива по поверхні горіння від зазначених змінних факторів у вигляді поліному другого порядку.

Отримані результати досліджень дозволять підвищити ефективність процесу виробництва теплоти з низькосортних твердих палив рослинного походження в котельних установках, сприятимуть їх більш широкому використанню, та підвищенню екологічної складової самого процесу.

Результати дослідження цікаві як для виробників котельного обладнання на рослинній сировині, так і для його користувачів, що мають за мету спалювати наявну в господарстві біомасу для задоволення потреб в енергії.

Ключові слова: *котельне обладнання, поверхня горіння, пневмомеханічний навантажувач, рослинна біомаса.*

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1. Introduction

Over the past decade, work has been actively conducted towards the creation of equipment operating on alternative energy sources, in particular biomass. Biomass has gained popularity among producers due to its high ability to restore, ecological purity and prevalence. The most obvious way to get energy from biomass is the technology of its direct combustion in boilers. This technology is sufficiently studied, relatively simple and commercially available [1]. However, the question remains of finding methods to increase the intensity and quality of combustion of low-grade fuels (corn rods and ears, husks of sunflower, lignin, grain straw, as well as pellets and briquettes based on them) [2]. Also important is the issue of increasing energy efficiency and environmental safety of the process of direct biomass burning in boilers [3].

These issues are trying to solve technological and constructive methods. In particular, the basic design features of boiler equipment are determined depending on the selected combustion technology [4, 5]:

– configuration and dimensions of the combustion chamber;
– geometric shape and method of cleaning heating surfaces;
– shielding degree;
– system for collecting and removing ash;
– system for capturing and removing volatile components.

Technological methods include [6, 7]:

– organization of the supply of blast gases to the combustion zone (one-, two- or three-stage) and step-by-step fuel combustion;
– methods for improving heat transfer in the convective part;
– flue gas recirculation;
– methods of supplying fuel to the combustion chamber of the boiler, etc.

Today, the technology allows using automation of biomass burning management to achieve effective indicators with a limited investment [8].

However, a significant reserve for improving biomass burning is the question of the uniform distribution of fuel from biomass over the combustion surface, which affects the intensity and quality of the fuel combustion process in boilers. The study of this issue will improve the efficiency of the direct combustion of biomass. Due to the uniform distribution of biomass over the combustion surface, the thickness of the fuel in the combustion chamber will be relatively the same, which will ensure a constant high temperature in the combustion zone and, as a result, the stability of the process of direct combustion of biomass in boilers.

Thus, the study of the process of uniform distribution of fuel over the combustion surface of the furnace chamber of the boiler is an urgent task, the solution of which will improve the efficiency of the process of burning fuel based on biomass.

2. The object of research and its technological audit

The object of research is the process of ensuring uniform distribution of fuel over the combustion surface of the combustion chamber of a solid fuel boiler operating on biomass. The existence of, under these conditions, a stable temperature in the combustion zone of the boiler combustion chamber is explained. It is emphasized that under these conditions, the danger of violating the stability of the combustion process due to local burning of the fuel and the formation of zones where the combustion process does not occur and the zones of hovering of the fuel disappears. It is noted that the design of means of supplying fuel to the combustion zone and the study of their technical and operational parameters will allow to regulate the process and increase the efficiency of heat production by burning low-grade fuel in the combustion chambers of boilers.

A certain drawback of the proposed solution, it becomes difficult to recommend a universal method for providing the above for most types of boiler equipment, through the excellent physical and mechanical properties of fuels and various boiler designs and their purpose.

One of the research problems is the lack of a sufficient theoretical base and practical experience in the process of chemical-thermal conversion of plant biomass to other types of energy. Work in this direction often boils down to determining the combined effect of the physicochemical characteristics of a certain type of plant material and the technical and operational parameters of a particular type of heating equipment on the performance of this equipment. The results obtained, as a rule, can be used during operation of only a certain category of heat engineering equipment with a similar purpose and similar technical and operational parameters for a given type of biomass.

The aforementioned is the reason for the containment of the widespread use of plant biomass for both energy production in heat engineering equipment in general and heat in solid fuel boilers in particular.

3. The aim and objectives of research

The aim of research is increasing the efficiency of the process of heat production from low-grade fuels in solid fuel boilers by ensuring uniform distribution of fuel on the combustion surface of the combustion chamber.

To achieve this aim it is necessary to solve the following objectives:

1. To design a loader of low-grade vegetable fuel in a solid fuel boiler.
2. Using a multivariate experiment, to determine the rational parameters of the distribution process of particles of low-grade vegetable fuel on the combustion surface of the boiler.

4. Research of existing solutions of the problem

The increase in global energy consumption and the need for sustainable industrial production indicate that renewable resources may become key participants in future energy development [9]. Biomass is the basis for a smooth transition from the use of fossil fuels to the development of the low-carbon technology market [10, 11]. However, energy production from plant biomass is associated with a number of difficulties, such as: heterogeneity of its structure; low specific energy content; high hygroscopicity, and, consequently, humidity; low melting temperature of ash and high windage [12, 13]. If to consider the simplest and most common method of producing thermal energy, then it consists in burning biomass in boilers in a fixed bed on grate sieves. In [14, 15], the combustion of a straw fuel mixture in grate boilers was studied. Studies have shown the effectiveness of straw burning as indicators of thermal and environmental efficiency. However, the authors of [15] note that a significant drawback of the use of grain straw is the formation of agglomerates from sintering of straw ash during its burning. One of the effective solutions to prevent sintering during the burning of straw is the use of fluidized bed combustion. Fluidized bed combustion minimizes the contact of fuel with the surface of technological equipment and does not allow the parts of the fuel to bake together.

An analysis of scientific works [16, 17] shows that a highly efficient and cost-effective way of generating heat from plant residues of agricultural production is the process of its direct combustion in solid fuel boilers with a circulating fluidized bed. One of the problems with the use of fluidized bed combustion is the need to achieve uniform distribution of the fuel mixture over the combustion mirror of the boiler. With an uneven distribution of fuel, local zones are formed that have different aerodynamic drags. In areas with a significant thickness of the fuel layer, the aerodynamic drag is correspondingly greater, which leads to a decrease for air supplied to the fuel. Also, in this zone, due to the lack of the required amount of air, energy release is reduced, which is accompanied by a decrease in the temperature of the fuel layer and deterioration of the conditions and completeness of fuel combustion.

Therefore, experimental studies play an important role in increasing the efficiency of the process of burning solid fuel from biomass by ensuring the least uneven distribution of raw material particles on the combustion surface.

5. Methods of research

5.1. Materials and equipment that for experimental studies. The study of the effect of uniformity of fuel distribution over the combustion surface of the boiler will allow

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to find the optimal parameters of the pneumatic mechanical loader of fuel, at which the intensity and quality of the combustion process will be high. This will allow to develop a technological scheme of the process of burning low-grade fuels from biomass and the design of an industrial design.

To conduct studies on the distribution of particles of low-grade vegetable fuel, previous studies were carried out to determine the geometric dimensions of the fuel spreading area. The length and width of the surface area, which accounts for the fall of the bulk of the fuel, were determined. The sizes were also determined for the distance of the idle zone, which amounted to 0.26 m. This is the distance from the nozzle of the pneumatic loader at which no fuel particles were dropped. The spreading area should cover an area that provides the recommended thermal intensity of the combustion device. The data obtained as a result of the studies were taken into account when conducting experiments on the uneven distribution of fuel particles in the combustion chamber.

In order to study the uneven distribution of fuel, an experimental bench was used, consisting of a boiler design with a rated power of 300 kW improved for a pneumatic loader (ALTEP TRIO «KT-3E» (Ukraine) Fig. 1, a support and a pneumomechanical loader converted to a boiler Fig. 2 (basic model of pneumomechanical thrower (PT)).

The boiler device ALTEP TRIO «KT-3E» has a number of structural solutions that allow to burn biomass in a circulating fluidized bed without any special structural alterations. The advantages of the boiler include the height of the combustion chamber 3, which is 1132 mm above the grate 9. Doors 7 located at a distance of 200 mm from the grate 9 make it possible to optimally dock the pneumatic loader through their opening and to supply fuel to the optimal super-scaffold area. This boiler implements a zone air injection through nozzles 5, which is regulated by blocking the air channels with manual air dampers 4. The air supply system of this boiler allows to shut off the air supply to the zone above the grate, to freely supply air to the flue zone and adjust the secondary air supply in the zone afterburning pyrolysis of them in the upper zone of the furnace. The microprocessor unit 21 allows for flexible regulation of the air supply.

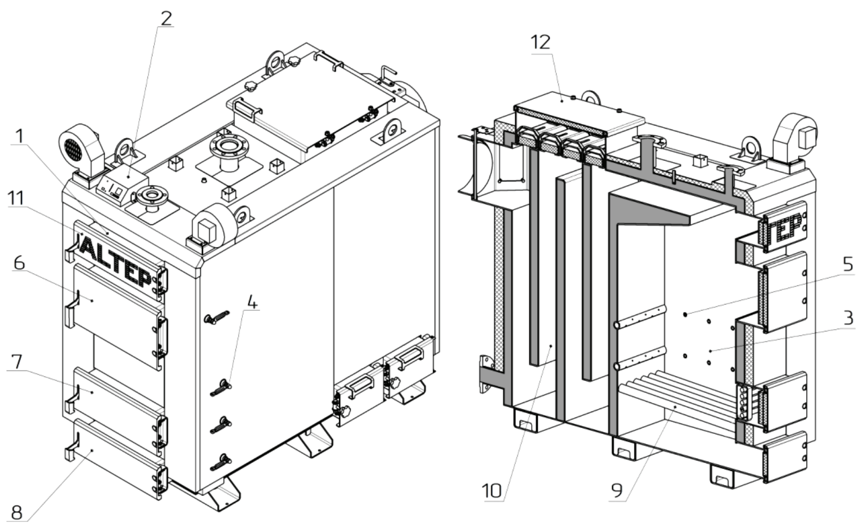
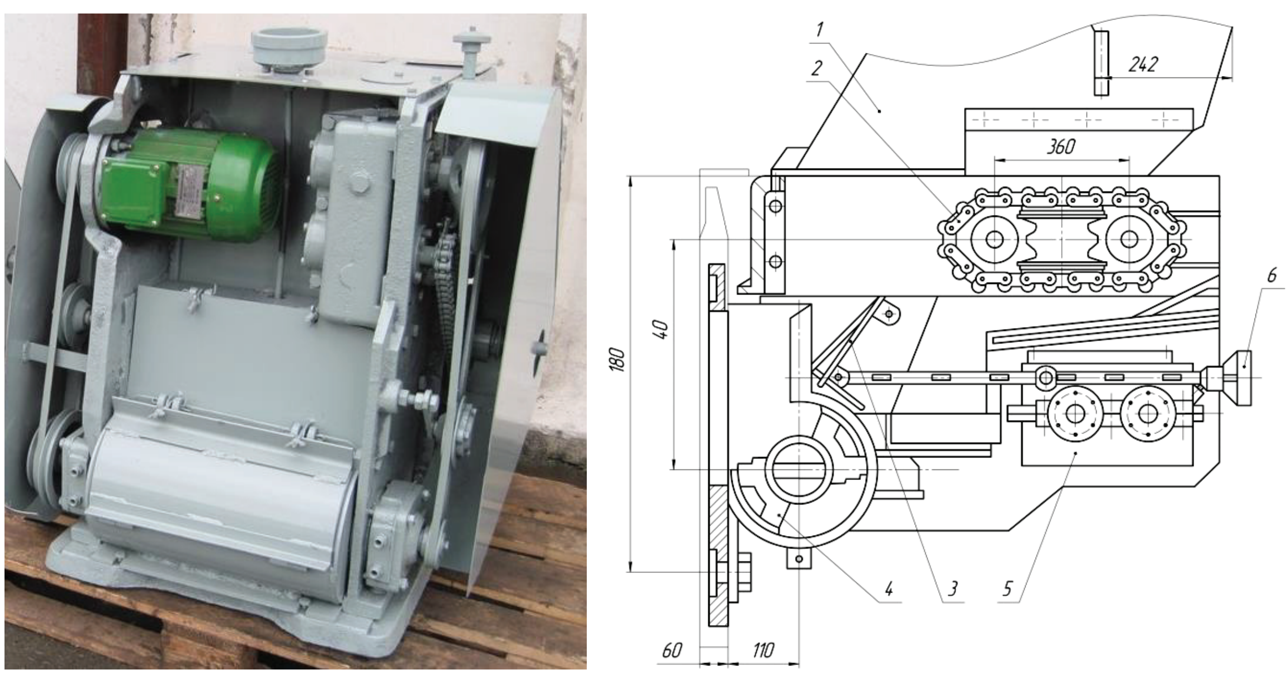


Fig. 1. Appearance and main elements of the ALTEP TRIO «KT-3E» boiler: 1 – boiler body; 2 – microprocessor control unit for the operation of boiler systems; 3 – combustion chamber; 4 – air damper control knobs; 5 – air supply nozzles; 6 – solid fuel loading door; 7 – revision doors; 8 – ash door; 9 – grate; 10 – convection heat exchanger; 11 – upper shelf doors; 12 – door of the boiler convection part



a *b*

Fig. 2. Pneumatic mechanical loader of solid fuel based on biomass: *a* – general view; *b* – assembly drawing: 1 – hopper for fuel biomass; 2 – feeder; 3 – regulating plate; 4 – rotor; 5 – pulse variator; 6 – throw distance regulator

A well-thought-out arrangement of doors 8, 11, 12 allows, if necessary, to carry out operational cleaning of the fountain space, horizontal and vertical walls of the convection heat exchanger, in the event of a sudden cessation of burning and the mass entering the confection heat exchanger.

A pneumatic-mechanical loader is included in the laboratory bench design with the aim of eliminating incomplete combustion of fuel mixtures, and therefore, reducing the phenomenon of chemical and mechanical under-inflammation, which is typical for fuels with a high content of volatile components. A pneumatic-mechanical loader feeds the fuel mixture into the combustion chamber by blowing it with a stream of air under pressure. Two streams of air with fuel mixtures, at the intersection, provide turbulence of particles in the furnace space. The mixing of the particles of the fuel mixture and the air flow introduced into the combustion zone by a pneumatic loader intensifies the combustion process. The air flow rate of the pneumatic loader is calculated in such a way that the speed at the outlet of the discharge pipe is higher than the greeting speed of the particles in the mixture. Due to the difference in the initial flow velocities, the direction of which intersects, particles are transported to the lower part of the combustion chamber and combustion of the fuel particles in suspension is ensured. The air flow rate at the outlet of the discharge pipe is 110 m^3/hour. The capacity of the pneumatic-mechanical loader can vary depending on the amount of air supplied through the grate. This is due to excess air pressure in the furnace chamber of the boiler. With an increase in the cost of the fuel mixture for the combustion process in the range of 70–120 kg/h, the air flow for the combustion process is in the range of 650–1000 m^3/h.

Using a support equipped with a protractor, the installation angle of the loader's discharge nozzle b and the height of the loader's nozzle above the plane H were determined, on which the fuel was thrown. In order to study the uniform and controlled supply of solid fuel for stratified combustion, a metal box is installed in the boiler furnace into the boiler combustion zone, which has the dimensions of the obtained fuel spreading sections. It is designed to study the height and area of dispersion of fuel in the combustion chamber of the boiler. The box dimensions 920–120–150 mm was divided into six identical sections 152–185–150 mm. The height of the fuel layer in the sections was measured with a metal ruler DSTU GOST 427:2009, installed in the center of the sections. The air flow rate at the outlet of the loader nozzle was measured using a Pitot tube with a Testo 512 micromanometer (Germany). According to the estimated indicator of the quality of dispersion, the coefficient of uneven distribution of fuel over the spreading surface was adopted m.

Mixtures made from hydrolytic lignin and wheat straw were used as fuel. The content of the main components in the hydrolysis of lignin in % by weight of absolutely dry matter was: 12.6–31.9 % polysaccharides, 48.3–72.0 % lignin, acidity in terms of H_2SO_4 – pH 2–2.5, ash content of 0.7–9.6 %.

Wheat straw was added to the fuel mixture as a multifractional composition with an average stalk length of 35 mm. The composition of straw with the content to dry weight of its main components: N=0.52 %, C=44.43 %, H=5.86 %, O=44.43 %, S=0.11 %, ash content – 6.5 %.

Depending on the content of straw and hydrolysis lignin, three types of mixtures were produced with the corresponding calorific value Q_H^p: mixture No. 1 – 70 % straw and 30 % hydrolysis lignin with $Q_H^p=16$ MJ/kg; mixture No. 2 –100 % sunflower husk with $Q_H^p=17.5$ MJ/kg; mix No. 3 – 100 % straw with $Q_H^p=13.5$ MJ/kg. Studies were conducted for each of the mixtures separately.

To achieve a rated power of 300 kW with an efficiency of 86 %, when working on fuel mixture No. 1, the boiler consumes about 78.5 kg/h of fuel, while working on fuel mixture No. 2 – 71.8 kg/h, No. 3 – 93 kg.

Taking into account the thermal tension of the combustion mirror $q=0.3$ MW/m^2 and the thermal voltage of the volume of the combustion chamber $q_V=0.310$ MW/m^2, the plane of the combustion mirror is 1 m^2 and the height of the combustion chamber is 1132 mm.

In a circulating fluidized bed under the action of the aerodynamic forces of the air stream, small particles of the fuel mixture become mobile in a certain volume above the grate. The air flow is supplied through the grate. At a certain air velocity, it is blown through the fuel layer, the pressure drop in the layer numerically becomes equal to the specific gravity of the particles. Particles of the fuel mixture begin to rely on the air flow, and not on the grate, as it was before. Due to the violation of adhesion between the particles of the fuel mixture, they become mobile, changing the porosity and height of the layer. The layer goes into a boiling state. When the pneumomechanical loader feeds, the fuel mixture acquires acceleration, which allows it to move to the grate, overcoming the lifting streams consisting of fuel, gasified, combustion products and a mixture of pyrolysis gases. In this case, the flows interact, creating turbulence of the fuel mixture in a fluidized bed. To feed the material into the combustion zone, the pneumatic mechanical loader uses flue gases, which are removed after the convection heat exchanger. The supply of the fuel mixture without the presence of oxygen in the stream allows to interact with the heated combustion products of the fuel without a combustion process. The burning of a new portion of fuel begins after mixing with air in a fluidized bed of raw materials.

Air was supplied to the air box of the combustion device and to the pneumatic loader by fans. In order to measure the total amount of air that was supplied to the combustion device, an air flow rate sensor was used, which was installed on a double-branch pipe. To measure the flue gas flow rate, the gas flow rate in front of the pneumatic loader was measured. Regulation of air flow in the furnace and flue gases to the pneumatic loaders was carried out by the corresponding air dampers.

The amount of fuel was determined by weighing it in a measured tank on a technical scale.

5.2. Methodology for processing the results of experimental research. The task was to establish the dependence of the uneven distribution of fuel on the surface of the combustion mirror m on the mass supply of fuel Q_f, height H and angle b of the discharge nozzle of the pneumatic loader over the plane to which it is fed. To establish the nature of the influence of variable factors on the uneven distribution of fuel on the surface of the combustion mirror according to the theory of planning a multivariate experiment, a non-compositional plan of the second order was adopted [18].

Levels and intervals of variation of factors are presented in Table 1.

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Table 1

Levels and intervals of variation of variable factors

Factors	Factor designation		Factor change levels			Factor interval
	natural	normalized	(–1)	(0)	(+1)	
Loader nozzle height, m	H	X_1	0.5	0.8	1.1	0.3
The angle of the discharge nozzle of the loader to the surface of the combustion mirror, deg.	β	X_2	–12	0	12	12
Mass fuel supply, g/s	Q_f	X_3	10	15	20	5

Note: designations of dependent factors: the height of the loader nozzle H, m – X_1; angle of inclination of the discharge nozzle of the loader to the surface of the combustion mirror β, deg. – X_2; mass fuel supply Q_f, m/s – X_3

The experiments were performed in triplicate with the mandatory use of randomization to reduce experimental errors.

Testing of reproducibility of experiments was carried out according to the Cochran's criterion [18]. In the case of non-fulfillment of the reproducibility condition by the Cochran's criterion, the measurement accuracy and experimental conditions were checked, as a result of which the maximum dispersion value was obtained [18].

In all experiments, the significance of the coefficients of the regression equations was evaluated by the Student criterion, the adequacy of the obtained regression equations was evaluated by the Fisher criterion [18]. The received data was processed using the «Solution Search» software of Microsoft Excel.

6. Research results

The uniform distribution of the fuel mixture over the combustion mirror is one of the conditions that ensures the completeness of fuel burnout. In order to study, multivariate experiments were carried out and the dependences of the non-uniformity coefficient m on factors influencing the distribution of fine-grained fuel mixtures were obtained. Studies were carried out for three fuel mixtures No. 1, No. 2, No. 3. The significance of the factors affecting the distribution of fuel mixtures over the spreading surface was established in accordance with the experimental design matrix. The values of the unevenness coefficients obtained for the experiment for various combinations of variable factors are presented in Table 2.

The mathematical description of the dependence of the distribution non-uniformity coefficient m on variable factors in the form of a second-order polynomial has the form:

– for fuel mixture No. 1:

$$\mu_1 = 0.926 - 0.005\cdot X_1 - 0.029\cdot X_2 - 0.026\cdot X_3 - 0.09\cdot X_1\cdot X_2 + 0.22\cdot X_1\cdot X_3 - 0.231\cdot X_2\cdot X_3 + 0.049\cdot X_1^2 + 0.029\cdot X_2^2 + 0.161\cdot X_3^2; \quad (1)$$

– for fuel mixture No. 2:

$$\mu_2 = 0.792 + 0.014\cdot X_1 - 0.016\cdot X_2 - 0.011\cdot X_3 - 0.1\cdot X_1\cdot X_2 + 0.154\cdot X_1\cdot X_3 - 0.211\cdot X_2\cdot X_3 + 0.034\cdot X_1^2 + 0.05\cdot X_2^2 + 0.113\cdot X_3^2; \quad (2)$$

– for fuel mixture No. 3:

$$\mu_3 = 0.69 - 0.015\cdot X_1 - 0.018\cdot X_2 + 0.007\cdot X_3 - 0.11\cdot X_1\cdot X_2 + 0.12\cdot X_1\cdot X_3 - 0.176\cdot X_2\cdot X_3 + 0.055\cdot X_1^2 + 0.07\cdot X_2^2 + 0.09\cdot X_3^2, \quad (3)$$

where X_1 – height of the nozzle above the combustion surface, m; X_2 – angle of the discharge nozzle to the combustion surface, deg; X_3 – mass fuel supply, g/s.

Table 2

Multivariate experiment planning matrix for determining the unevenness coefficient

No.	Experiment planning method				Experiment results		
	X_0	X_1	X_2	X_3	μ_{1av}	μ_{2av}	μ_{3av}
1	+	+	+	0	0.922	0.800	0.708
2	+	+	–	0	1.201	1.074	0.981
3	+	–	+	0	0.987	0.873	0.867
4	+	–	–	0	0.905	0.758	0.695
5	+	0	0	0	0.878	0.818	0.704
6	+	+	0	+	1.323	1.083	0.921
7	+	+	0	–	0.874	0.705	0.607
8	+	–	0	+	0.958	0.865	0.822
9	+	–	0	–	1.387	1.103	0.981
10	+	0	0	0	0.911	0.797	0.662
11	+	0	+	+	0.803	0.671	0.631
12	+	0	+	–	1.377	1.209	1.031
13	+	0	–	+	1.317	1.123	1.015
14	+	0	–	–	0.967	0.816	0.713
15	+	0	0	0	0.990	0.761	0.700

The tabular value of the Cochran's coefficient is $G(0.05;\ n;\ f_U)=0.5157$ for a 5 % significance level, the number of experiments $n=8$ and the number of degrees of freedom of each experiment $f_U=2$ with $m_0=3$ repetitions [19]. Estimated Cochran's coefficient:

– for fuel mixture No. 1 – $G=0.432<G(0.05;\ n;\ f_U)=0.5157$, which indicates the reproducibility of the experiments;

– for fuel mixture No. 2 – $G=0.388<G(0.05;\ n;\ f_U)=0.5157$, which indicates the reproducibility of the experiments;

– for fuel mixture No. 3 – $G=0.345<G(0.05;\ n;\ f_U)=0.5157$, which indicates the reproducibility of the experiments.

The calculated value of the Fisher coefficient is:

– for fuel mixture No. 1 – $F=2.04<F(0.05;\ f_{ad};\ f_y)=19.3$;

– for fuel mixture No. 2 – $F=9.05<F(0.05;\ f_{ad};\ f_y)=19.3$;

– for fuel mixture No. 3 – $F=17.5<F(0.05;\ f_{ad};\ f_y)=19.3$.

So the models are adequate and can be used to describe the object.

To determine the values of factors at which the function assumes the maximum value, dependencies (1)–(3) were rationalized using the Microsoft Excel solution solution search service [19].

If the speed of the mixture of fuel and air in the loader's pipeline is close to critical, to ensure the minimum unevenness of fuel dispersion, the angle of inclination of the discharge nozzle to the combustion surface should be adjusted. For chopped straw, this angle is –12...–6 degrees, for husk of sunflower – –10...–6, for a mixture of straw with lignin – –8...+2 degrees. In this case, the feed rate of the mixture for straw chopping should be within 10 m/s, for husks of sunflower – 13 m/s, and for a mixture of straw with lignin – 15 m/s. It should be noted that the nature of the variation in the coefficient of unevenness for chopped straw and husks of sunflower are similar, in contrast to a mixture of straw with lignin.

The obtained dependencies can be used when choosing the operating mode and the location of the main nodes of the fuel loader, which provide the least unevenness. The main indicator on which the choice of the loader operation parameters depends is the critical speed of the mixture in the loader tube (the speed of the mixture must be greater than or equal to the critical).

7. SWOT analysis of research results

Strengths. Among the strengths of this research, it should be noted that practical results were obtained regarding the combustion in solid fuel boilers of low-grade fuels of plant origin, such as grain straw, lignin and sunflower husk. It is established that the best quality and intensity of the combustion process can be achieved by burning these types of fuel in boilers with a circulating fluidized bed. The technical and operational parameters of the boiler equipment for this type of biomass are obtained. Since these types of biomass are the most common in small agricultural and farming enterprises, the results can be used by manufacturers of boiler equipment in the manufacture of new highly efficient and environmentally friendly equipment samples for this energy sector of the market. The practical results obtained will allow to optimize the process of designing boiler equipment by unifying parts and assemblies like a combustion chamber, a grate, a loading pipe of raw materials and the like. The use of standardized parts and assemblies will primarily affect the speed of product design, not only within the same model line, but also of other related and unrelated areas and purposes. As a result, there is a significant reduction in the cost of such equipment and its price for the consumer, increasing the competitive ability of the final product.

Weaknesses. Among the weaknesses, one can single out the lack of a thorough mathematical description of the obtained practical results. Also, the research results can be applied in the design and improvement of only boiler equipment and loaders operating on plant materials with similar physical and mechanical properties and calorific value. A constantly developing market for energy equipment requires the creation of new universal highly efficient boiler equipment for any type of biomass.

Opportunities. The use of the obtained practical results has significant prospects for describing and further modeling the process of burning solid low-grade biofuel, taking into account the laws of conservation of mass and energy for the components of the mixture. Significant results can be obtained for carrying out a theoretical analysis and modeling of the operating parameters of the combustion device, and analysis of the aerodynamics of the fuel-and-fuel supply system.

Prospects for further research in this direction should be focused on the development of engineering methods for calculating furnace devices with pneumatic mechanical fuel loaders, which will take into account the peculiarities of feeding and burning fine-grained fuel from biomass. And also to create a base of unified parts and components for universal boiler equipment and a fuel-and-fuel supply system for a wide range of plant biomass with various physical and mechanical properties.

Threats. The main threats to the widespread use of the results are the rapid development of technologies for chemical-thermal conversion of biofuels and requirements for the operational parameters of thermal power equipment, which are extremely dynamic. In addition, the use of a wide line of boiler equipment with a circulating fluidized bed, equipped with a pneumatic loader, is advisable for fuels with high windage within small and medium-sized agricultural and farming enterprises. The design of powerful high-performance boiler plants based on the indicated technical technique requires significant investments, it is available only to a certain category of consumers.

8. Conclusions

1. The design of a loader of low-grade vegetable fuel with a mass fuel supply in the range of 36–72 kg/h to the solid fuel boiler ALTEP TRIO «KT-3E» is developed. The difference between the loader is the possibility of adjusting the angle of the discharge nozzle for fuel in the range of –12–12 degrees, the mass supply of fuel using the shutter and the height of the discharge nozzle for fuel above the surface of the combustion mirror within 0.5–1.1 m. For wheat straw this height is 0.5 m, for sunflower husk 0.8 and for a mixture with 70 % straw and 30 % hydrolysis lignin, the height is 1.1 m. It is established that the use of a pneumatic-mechanical loader ensures uniform distribution of the fuel layer in the furnace room In addition, the intensity of the movement and the quality of the combustion process improves. The overall efficiency of using a solid fuel boiler equipped with a loader is growing by 13.6 %.

2. By conducting a multivariate experiment, the influence of the mass supply of fuel, the installation height and the angle of the discharge nozzle for the fuel to the combustion surface on the coefficient of uneven distribution of fuel on the spreading surface is investigated. If the speed of the mixture of fuel and air in the loader's pipeline is close to critical, to ensure the minimum unevenness of fuel dispersion, the angle of inclination of the discharge nozzle to the combustion surface should be adjusted. For chopped straw, this angle is –12...–6 degrees, for husk of sunflower – –10...–6, for a mixture of straw with lignin – –8...+2 degrees. In this case, the feed rate of the mixture for chopping straw should be within 10 m/s, for husks of sunflower – 13 m/s, and for a mixture of straw with lignin – 15 m/s.

The corresponding regression dependencies are obtained for each investigated parameter.

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