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# EXPERIMENTAL STUDIES OF BURNING PELLETS IN A BURNER UP TO 30 KW

***Abstract:*** *Given the world trends in the use of biofuels of agricultural origin, Ukraine has considerable potential to develop this direction at the expense of a significant resource base. Solid biomass is mainly used for heat production in large or medium-sized district heating boilers and in domestic wood, pellet boilers, in furnaces and in fireplaces.*

*The work is devoted to the research of burning of wood pellets and agropellet (from rape straw) with the purpose of improvement of operational and ecological indicators of household boilers with capacity up to 30 kW. Results of experimental research of burning of mentioned pellets are given on the basis of data of experiment characteristic features of temperature conditions in heating volume of boiler and burning at burning of pellets are defined.*

***Keywords:*** *bioenergy, biomass, agrobiomass, straw, crop residues, by-products of crop production, agropellet, rape straw*

## Introduction. Brief analysis of recent publications

Almost one-third of the fuel needs of municipal heat power engineering Ukraine is satisfied by imported natural gas. Part of it can be replaced by using biofuel of agricultural origin [1]. It is important to realize this in conditions of economic crisis, necessity of import substitution and the most severe economy of fuel and energy resources, especially in military time.

Biomass, including commercial agricultural waste, plays an important role in achieving the EU target [2] of 32% renewable sources in total energy consumption by 2030. According to [3], biomass, in combination with solar thermal and wind energy, has the greatest potential in the energy goals of the EU until 2050 (full coverage of energy needs for heating and cooling, reduction of greenhouse gas emissions by 80-95%).

Currently, Europe accounts for more than 50% of the world demand for pellets. As of 2020, pellet use in European countries included residential heating (40%), power plant needs (36%), commercial heating (14%) and cogeneration (10%). Heating system held a significant market share in 2020 and is likely to dominate in the near term (Fig. 1). In addition, pellets are also used in projects to replace coal in buildings owned by local authorities or public administrations, such as: schools and offices. As of 2020, most co-fired power plants have either closed or converted, with some switching entirely to wood pellets as fuel. The largest of these is the Drax power station in North Yorkshire (UK), which has converted four of its six 65 MW units to run exclusively on biomass and is currently evaluating options for the remaining two coal-fired units.

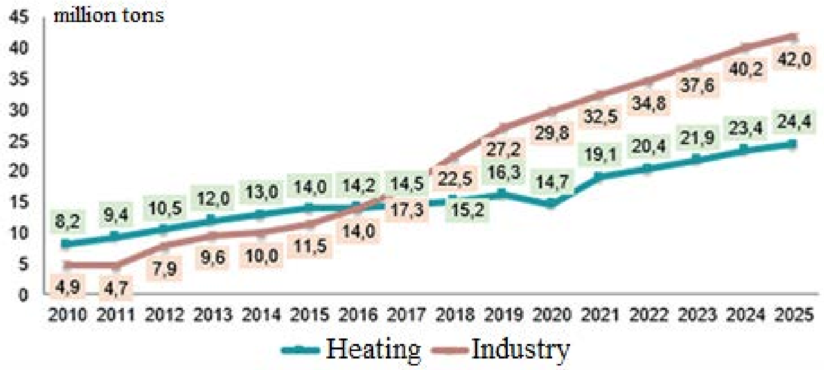



***FIGURE 1.** Dynamics of world consumption of pellets in 2010-2018 forecast for 2019-2025, million tons [4]*

The sales volume in the European pellet market in 2020 reached 8.92 million dollars. It is expected to grow by 15% between 2021 and 2027. The demand for pellets will be driven by the increase in the number of facilities generating energy from alternative sources.

Another factor in the increase in demand was the properties of the wood pellets themselves. They have lower moisture content and less ash residue than traditional fuels such as coal. Despite the difficulties with transportation, pellets have their stable demand in the USA and Europe. In particular, the expected demand for pellets in Europe will reach 70 million tons by 2027. The industrial sector will consume about 35% of the total volume of manufactured pellets, because there is a trend for the construction of heat and power generating plants and their conversion from coal consumption to pellets [5].

In addition to wood, solid biomass can also be taken from agriculture (to produce agricultural pellets) [6]. Currently, the main sources of biomass in Ukraine are agricultural waste and residues (straw of cereal and technical crops, stalks and stalks of corn, stalks, and husks of sunflower), as well as in the future – energy crops (willow, poplar, miscanthus, etc.) that are specially grown [7].

Rape residues are characterized by several disadvantages, so they cannot be used in animal feed and bedding. Therefore, rape began to be used as an effective and inexpensive source of energy. In the conditions of constantly rising energy prices, this opens more and more benefits, new types of fuel are being developed on the basis of rapeseed and existing ones are being improved.

The possibility of producing pellets from rapeseed straw is under consideration. According to the volume of cultivation and export of rapeseed, Ukraine is firmly in the top ten world leaders. In particular, last year Ukraine harvested almost 2.8 million tons of rapeseed and was in 7th place among the leading producing countries. Over the past two years, the area under rapeseed in Ukraine has increased by as much as 62%: from 0.8 million hectares in 2017 to 1.3 million hectares in 2019. During this time, the average yield of rape increased from 2.5 t/ha to 2.76 t/ha, and the productivity of rape straw was approximately the same.

It is worth noting that Canada, the EU, China, Japan, and India are among the TOP-5 world producers of rapeseed (Fig. 2). This year, production indicators may change significantly. This was affected by the prolonged drought in several European countries. Experts claim that the area sown under rapeseed has significantly decreased in the EU. Production estimates are down for France, Romania, and Hungary, but up slightly for the UK and Slovakia, as the overall water balance in the EU worsens, despite a slight improvement in Southeast Europe. The situation on foreign markets can significantly affect economic forecasts for Ukrainian farmers [8].

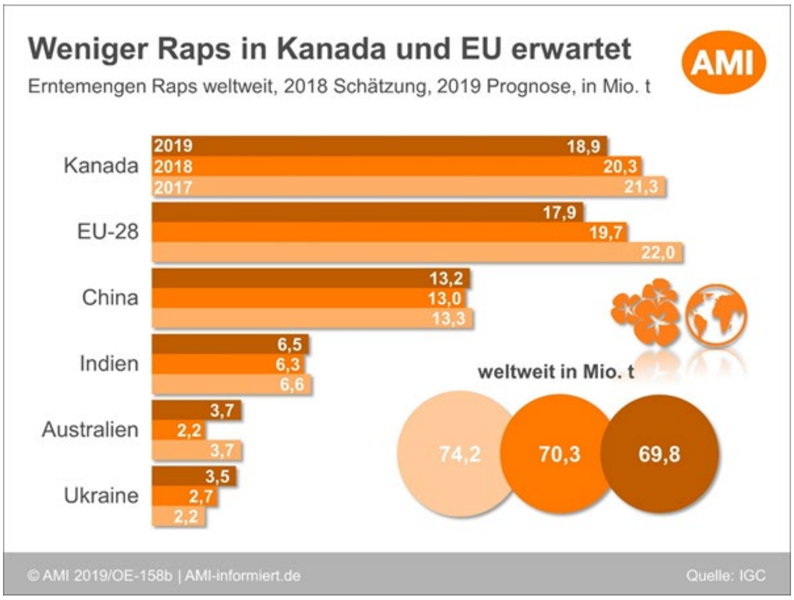



***FIGURE 2.*** *Sown areas under rapeseed in the world*

The use of biomass as a fuel in the production of thermal energy to meet the needs of heating and hot water supply provides significant economic advantages, because it will reduce heating costs, as well as reduce greenhouse gas emissions by more than 8.0 million tons of $CO_2$-eq.

The successful technical implementation of the pellet burning process relates to the choice of rational technical solutions and operational parameters of the corresponding equipment. Therefore, the improvement of technologies and equipment for burning biofuels of agricultural origin is an urgent task, which is due to the ecological state of the environment and the need to involve alternative and renewable energy sources in the energy industry in connection with the depletion and constant growth of prices for fossil energy carriers.

Considering the relevance of the study of the process of burning biofuel, the Institute of Engineering Thermophysics, National Academy of Sciences of Ukraine developed and tested an experimental installation of a solid fuel boiler with a pellet burner for heating an experimental house of the passive type [9, 10]. The main goal of this study is to determine the main regularities of the combustion process of agropellets of agricultural origin and to study the influence of regime parameters on the temperature distribution in the combustion chamber, as well as to study the productive characteristics of biofuel raw materials.

## Object, subject, and methods of research

The developed experimental installation based on a solid-fuel boiler of the Viadrus type with a thermal capacity of 30 kW with an original pellet burner allows for a thorough investigation of the burning characteristics of various plant-based fuels for home heating (Figs. 3, 4).

The temperature is measured using a comb of Chromel/Alumel thermocouples with an open junction, located at different distances from the initial cross-section of the burner (Fig. 5). The temperature measurement error was no more than ±0.5 K. During all tests, the water supply temperature from the boiler stabilized at 65°C ±1°C.

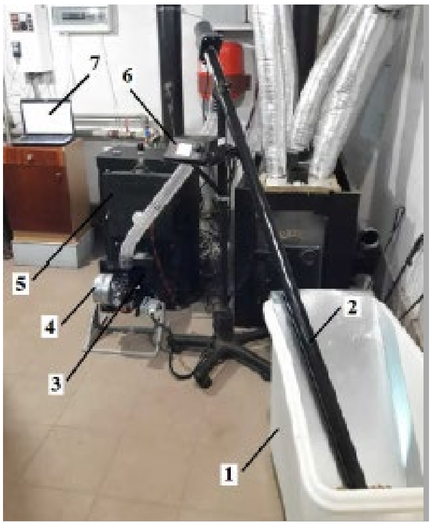



***FIGURE 3.*** *Experimental installation of a pellet burner for burning vegetable pellets: 1 – loading hopper; 2 – external auger for transportation of biofuel; 3 – pellet burner; 4 – fan; 5 – solid fuel boiler; 6 – boiler control unit; 7 – unit of measurement and archiving of experimental data*

***FIGURE 4.*** *Automatic burner with a movable scraper*

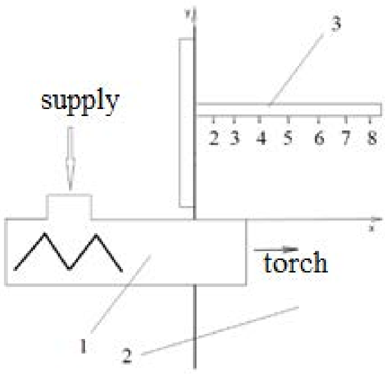



***FIGURE 5.*** *Temperature measurement scheme: 1 – pellet burner; 2 – furnace space of the boiler; 3 – comb of thermocouples located above the burning torch*

The fuel supply rate is set in manual mode to obtain continuous operation with a small amount of combustible elements in the remainder. The consumption of pellets coming from the hopper to the combustion chamber is regulated by the electronic control unit of the solid fuel boiler. It can also be used to adjust a number of boiler operation parameters: boiler operation power, maximum and minimum fan performance, operating time of the internal auger in the burner when feeding pellets into the high-temperature zone, parameters for cleaning the burner floor with a movable scraper.

The residues collected after the heating plant tests were also analyzed to determine their composition and carbon content (representing the unburned carbon content of the bottom residue).

During each test period (for the same type of fuel), the feed rate is constant, which is determined by the duration and frequency of the screw conveyor.

***Measurement of emissions.*** After reaching stable operating conditions, CO, $NO_x$ concentrations expressed on a dry basis were measured using a TESTO type 330-1LL gas analyzer. NOx emissions during combustion are formed mainly in the form of NO, the content of nitrogen dioxide is on average 5%.

## Study results and their discussion

The article focuses on the following types of pellets: wood pellets and rapeseed pellets.

When burning wood pellets, ignition occurred within the first 300 seconds. The fuel is ignited by a special igniter. After ignition, the pellets begin to burn, and the temperature value in the volume of the boiler begins to gradually increase. The largest increase in temperature occurs near the front wall of the boiler, which is opposite to the burner. At the moment of time 2550 s from the beginning of the experiment, the maximum temperature values reach 680°C (Fig. 6, thermocouple No. 8).

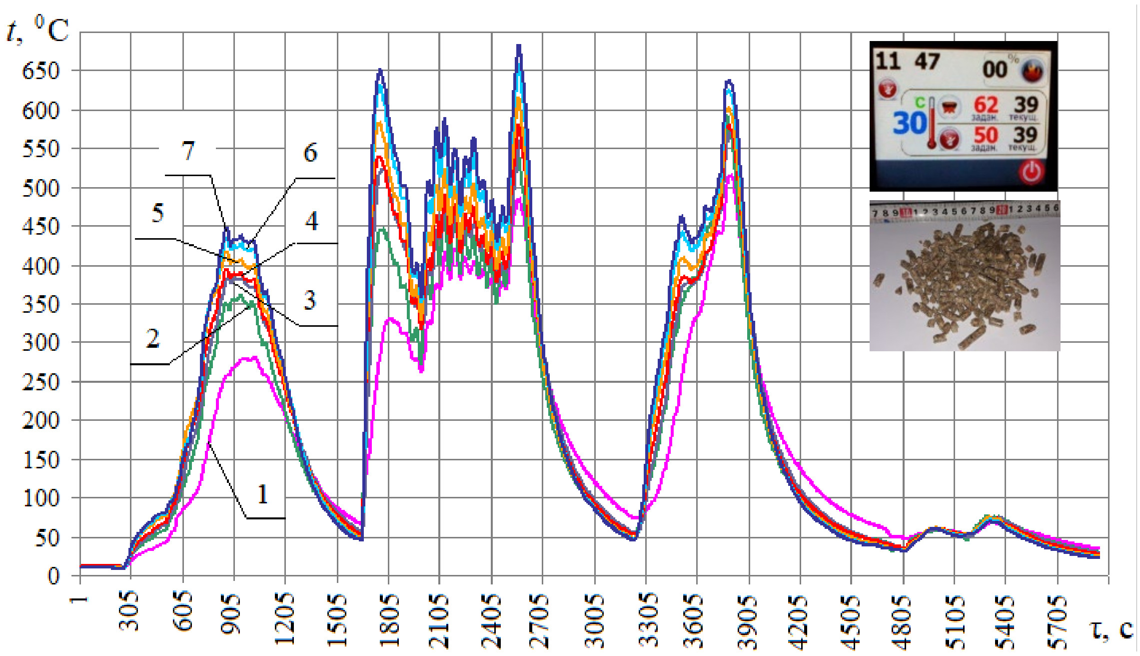



***FIGURE 6.*** *Temperature of combustion products in the high-temperature zone of the combustion chamber when burning wood pellets: 1-7 – temperature values measured by thermocouples No. 2-8, respectively (see Fig. 5)*

From 2105 s to 2500 s of the experiment, a stable burning process of wood pellets takes place. The average temperature of flue gases is 260°C. During this time, there was an automatic periodic supply of pellets from the bunker according to a programmed algorithm. At the same time, the temperature fluctuated within the following limits:

- thermocouples No. 4-8 – 400...590°C;
- thermocouples No. 2-3 – 350...450°C.

Temperature fluctuations occur as a result of the periodic burning of a portion of biofuel in the burner and the arrival of a new portion of pellets from the bunker. The burner is extinguished by selecting the "Extinguishing" menu item in the controller. As can be seen from the graph, a gradual decrease in the temperature in the boiler chamber and flue gases begins. After extinguishing, the corresponding symbol appears on the controller display.

In a similar way, as in the previous experiment with the burning of wood pellets, the results of the study of the burning of agricultural pellets from rapeseed straw were obtained (Fig. 7). In this case, a lower temperature level is realized (thermocouples No. 2-6) compared to wood fuel. The measured values are in the range of 120...250°C at a steady burning mode (720-2000 s).

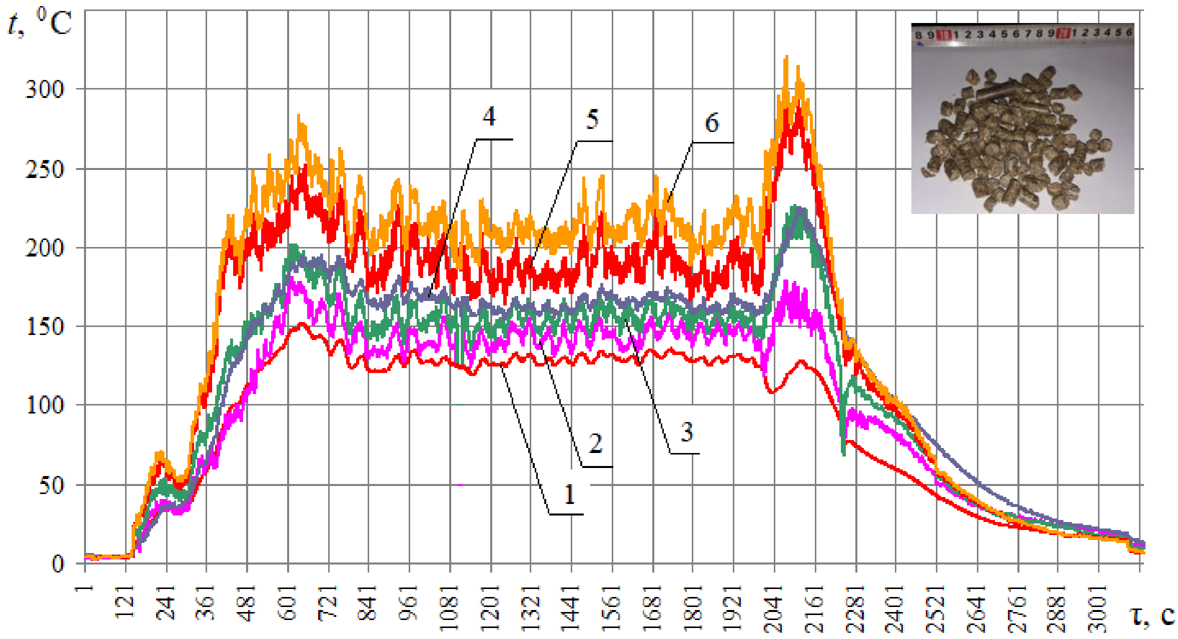
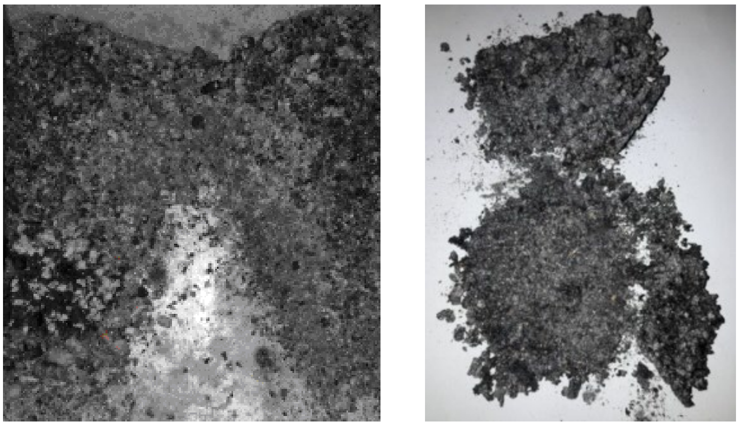



***FIGURE 7.*** *Temperature of combustion products in the high-temperature zone of the combustion chamber during rapeseed burning: 1 – flue gas temperature; 2-6 – temperature values measured by thermocouples No. 2-6*

At the end of each experiment, the remains of fuel ash were photographed (Fig. 8).



a) b)

***FIGURE 8.*** *Ash residue during burning: a) wood fuel pellets; b) pellets from rapeseed straw*

The gas analysis was carried out during the burning of wood pellets. The selection of combustion products was carried out in the chimney immediately after the boiler. As a result, the $NO_x$ and CO concentrations of the corresponding temperature at the sampling site were obtained. The change over time in the concentration of these substances in flue gases is shown in Figure 9.

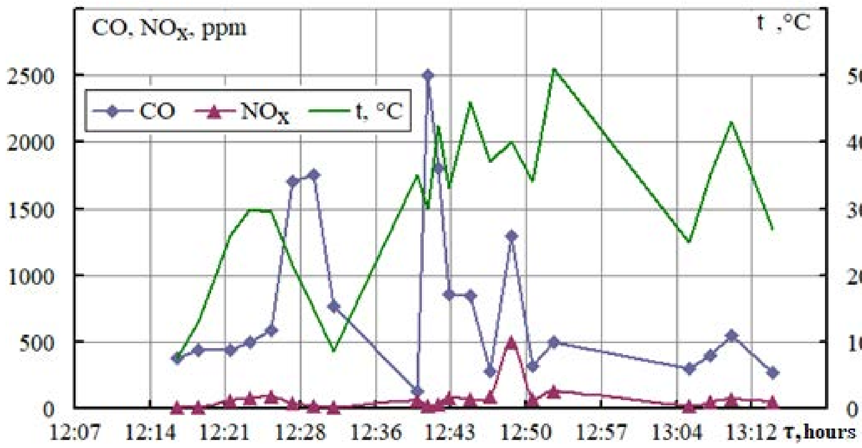



***FIGURE 9.** Concentrations of $NO_x$ and CO in waste gases during burning of wood pellets*

The values of concentrations of nitrogen oxides should be considered moderate, which cannot be said about the concentration of carbon monoxide. Such a picture is characteristic of the process of low-temperature combustion with the presence of significant chemical underburning. It was found that a significant concentration of CO is realized in the transitional phases of fuel supply, its ignition and extinction. Concentration maxima correspond to transitional processes between ignition and steady burning. In general, concentrations of CO as the main component of chemical underburning have an inflated level and require further correction by adjusting the operating modes of the burner system and, if possible, implementing additional constructive measures.

It should be noted that the reduction of CO emissions due to incomplete combustion can be achieved by extending the residence time of combustion products (especially in parts with a sufficiently high temperature >550°C), by additional turbulence of the flow or by achieving higher temperatures of combustion products in certain parts of the water heating boiler. Since the residence time of products is determined by the speed of fuel supply and the design of the combustion chamber, it is almost impossible to significantly influence it. One of the options for solving the given problem can be proposed measures that cause a local increase in the turbulence of the flow or an increase in the temperature of the flue gases. As an option, the authors of [11] (Fig. 10). The recommended location is in a region of high enough temperatures to potentially support relatively high CO burning rates.

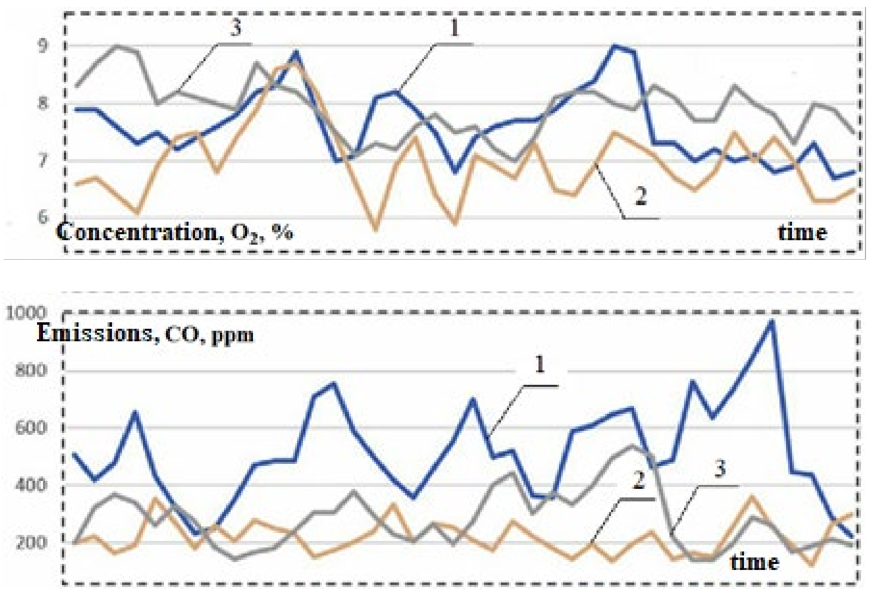



***FIGURE 10.** Concentrations of CO and $O_2$ in the waste gases during the combustion of agricultural pellets (1) when using grid combustion turbulators of a honeycomb shape (2) and V-shaped turbulators (3) [11]*

## Conclusion

It has been established that when combining a solid fuel boiler and the proposed burner (low power – up to 30 kW), it is possible to burn a wide range of pellets of plant origin.

Variations in physical and chemical properties among the pellets used are relatively large. It was established that the mechanical strength and bulk mass are lower than the limit values. This can cause pellet transport problems and burner clogging. The latter can cause problems with burner control.

The ash content for agricultural pellets ranged from 4.4% to 7.6%.

During the research, optimal combustion mode maps were established depending on the completeness of combustion, emissions of harmful gases ($NO_x$), ash structure, and coolant temperature. The composition and concentration of the components of waste gases, as well as possible regimes in which condensation of water vapor occurs, were studied.

In the future, the results of the research can be used to increase the efficiency of the combustion process when burning biofuel and to modernize fuel-burning systems of low-power boilers of communal and industrial heat energy, the social-budgetary sphere, the individual-household sector, etc.

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