Plywood production wastes to energy

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Abstract. Wood and by-products of its processing are a renewable energy source with carbon neutral and may be used in solving energy problems. ZAO «Arkhangelsk plywood factory» installed and put into operation the boiler with capacity of 22 MW (saturated steam of 1.2 MPa) to reduce the cost of thermal energy, the impact of environmental factors on stability of the company's development and for reduction of harmful emissions into the environment. Fuel for boiler is the mixture consists of chip plywood, birch bark, wood sanding dust (WSD) and sawdust of the plywood processing. The components of the fuel mixture significantly differ in thermotechnical characteristics and technological parameters but especially in size composition. Particle dimensions in the fuel mixture differ by more than a thousand times which makes it «unique» and very difficult to ensure the effective and non-explosive use. WSD and sawdust from line of cutting of plywood are small fraction material and relate to IV group of explosion. Criterion of explosive for them has great values ($K_{WSD}=10.85$; $K_{sawdust}=9.66$). Boiler’s furnace equipped with reciprocating grate where implemented a three-stage scheme of combustion. For a comprehensive survey of the effectiveness of installed equipment was analyzed the design features of the boiler, defined the components of thermal balance, studied nitrogen oxide emissions, carbon and particulate matter with the determination of soot emissions. Amount of solid particles depending on their shape and size was analyzed.

1. Introduction
By-products formed at all stages of technological processes of timber processing can be used industrially in various directions without disruption of ecological balance. Therefore, the substitution of fossil fuels by biofuel is actively encouraged in industrialized countries to reduce the impact of "greenhouse" gases on the planet's climate.

ZAO «Arkhangelsk plywood factory" in 2015 was installed and put into operation boiler PRD 22000 by Austrian company «Polytechnik Luft- und Feuerungstechnik GmbH» in order to reduce the cost of thermal energy production, to reduce the influence of environmental factors on the sustainability and stability of the company’s development and for the integrated reduction of harmful substances emissions into the environment.

2. Research plant and experiments
The boiler is installed in a production boiler house designed to provide steam for the technological cycle of plywood production. The boiler is equipped with an individual chimney height of 34 m and an automatic control system for all processes. The process scheme of the boiler shown in Fig. 1. This boiler produces saturated steam at a working pressure of 1.2 MPa, its nominal capacity 34 t/h.
Fuel for boiler is the mixture consists of chip plywood, pitch bark, veneer, WSD, sawdust of the plywood processing. The components of the fuel mixture significantly differ in thermotechnical characteristics (moisture, ash content, calorific value) and technological parameters (fractibility, explosion hazard), but especially in size composition [1]. Particle dimensions in the fuel mixture differ by more than a thousand times which makes it «unique» and very difficult to ensure the effective and non-explosive use of energy. WSD and sawdust from line of cutting of plywood are small fraction material and relate to IV group of explosion. Criterion of explosive (\(K_f\)) for them has great values (\(K_f^{WSD}=10.85; K_f^{saw}=9.66\)). Thus, the composition of the burnt wood fuel complicates operating conditions of the boiler PRD 22000. An energy inspection of boiler house was carried out for a comprehensive assessment of the efficiency of the installed equipment. Capacity of the boiler changed in the ranged of 89-96% of the nominal value.

The boiler house has fuel storage and is equipped with a fuel supply system. Fuel using pushers is fed to the drag-chain conveyor which is provides fuel supply to the fuel feeding bell of the automatic feeder. The fuel feeding bell is used to supply the pusher with fuel which ensures its transportation through the feeding device to the grate of the combustion chamber into the evaporating zone. Loading of the combustion device is carried out in the clock mode, depending on the consumption of heat by consumers, the composition and moisture of the fuel.

The furnace is equipped with a reciprocating grate. Heat liberation rate of fuel-burning area was 0.746-0.802 MW/m². Four zones with individual supply on the one side of primary air and the other side of recycled flue gases are organized below the grate by means of partitions. The supply of hot air after the air heater to each of the grate zones is carried out by means of an individual fan. Air to the secondary forced draft is supplied into the combustion chamber through nozzles of a cylindrical shape. The nozzles are staggered on the side walls. A three-stage fuel combustion is implemented in the chamber of the boiler. Two recirculation systems of combustion products are installed to further reduce emissions of nitrogen oxides and improve the reliability of the grate and settings. The intake of combustion products in the recirculation line is carried out from the flue after the main exhauster. Combustion products using a recirculation exhaust fan №1 are sent to the chamber above the grate from the side walls. The recirculation gases are fed under the grate zonally by means of a recirculation fan №2. The total quantity of recirculation gases was 0.35-0.40. All forced draft installations have frequency regulation.

The boiler is equipped with two-way flue-tube steam generators which located horizontally along the longitudinal axis above the combustion chamber. The combustion products at the outlet from the furnace are divided into two streams and entered the steam generators. During the energy survey, the saturated steam temperature at the outlet from the steam generators was 189-191 °C. The inlet
temperature of the gases in the steam generators varied in the range 850-868 °C, and after them 231-244 °C (Table 1). The walls of the combustion chamber are made of refractory fire-clay lining. One intermediate arch is installed in the furnace to increase the residence time of the flue gases.

The combustion products make two passes in the channels of the combustion chamber and enter the water-cooled reversing chambers of the steam generators when turn 90° and make two passes inside the fire tubes. After that the combustion products enter the gas-distribution chamber of the economizer and which are directed downwards passing through 400 pipes and giving heat to the feed water.

3. Results and discussion

During the energy survey, the average gas velocity for the first pass in the steam generators was 16.4-17.0 m/s; it rises to 17.5-18.2 m/s for the second pass. In the investigated range of loads, the gas velocity in the pipes of the economizer was 15.8-16.4 m/s.

After the economizer flue gases enter the multicyclone RGE 22000 and are cleaned of particulate matter. Filtered flue gas is sent to the recuperative tubular air heater LUVO 22000 in which it makes two passes and provides heating of the primary air. Heating surface of the air heater is 470 m².

The boiler is equipped with an air blasting system for cleaning from the ash particles of the tubes of steam generators, economizer and air heater. However, the period of continuous operation between the stops for cleaning the heating surfaces is no more than two months. The selection and X-ray fluorescence spectroscopy of the ash deposits from the inlet part of the fire tubes of the first pass of the steam generators was carried out to determine the causes of this fact. The formation of dense deposits occurs precisely in this zone which limit the period of operation of the boiler between cleaning.

| Table 1. Results of tests of the boiler PRD-22000 |
|-----------------|--------|--------|--------|
| Value (dimension) | Test №1 | Test №2 | Test №3 |
| Capacity (MW) | 20.2 | 20.5 | 21.7 |
| Working pressure of saturated steam (MPa) | 1.15 | 1.15 | 1.15 |
| Feed water temperature (°C) | 106.7 | 106.5 | 106.5 |
| Working pressure of feed water (MPa) | 1.53 | 1.53 | 1.53 |
| Fuel moisture, W_f (%) | 26.74 | 26.74 | 26.74 |
| Fuel ash content, A_d (%) | 0.45 | 0.45 | 0.45 |
| Low calorific value, Q_c(MJ/kg) | 13.22 | 13.22 | 13.22 |
| Primary air temperature (°C) | 80.0 | 80.0 | 80.0 |
| Gas temperature at economizer inlet / outlet (°C) | 244/168 | 236/168 | 231/168 |
| Gas temperature at air heater inlet / outlet (°C) | 165/151 | 165/151 | 164/150 |
| Air-fuel ratio in flue gas | 1.79 | 1.69 | 1.86 |
| Heat loss with: | | | |
| the stack gases (%) | 9.49 | 8.98 | 9.87 |
| incomplete combustion (%) | 0.01 | 0.01 | 0.01 |
| combustibles (%) | 0.13 | 0.13 | 0.14 |
| external heat(%) | 0.61 | 0.60 | 0.56 |
| Gross efficiency (%) | 89.75 | 90.26 | 89.40 |
| Total fuel consumption (t/h) | 6.121 | 6.177 | 6.593 |
| EmissionNO_x (mg/MJ) | 64 | 62 | 67 |
| Emission CO (mg/MJ) | 12 | 12 | 11 |
| Emission of suspended particles (mg/MJ) | 62.84 | 57.08 | 60.83 |

The results from the analysis showed an increased content of calcium, potassium and sodium oxides in the ash deposits (Table 2), which strongly influenced the fly ash fusion characteristics. According to [2], fuels with CaO>13.0% in their ash composition are highly polluting. At the content of oxides of alkali metals Na_2O + K_2O>3.1%, the evaporation temperature of which is 800-1000 °C, bonded deposits form on the heating surfaces. The grinding material and binding resins in the WSD also contributes to the intensification of contamination of the fire tubes. Studies have shown [3] that particles of abrasive...
material have a size of less than 45 μm and are removed by combustion products from the volume of combustion chamber.

Table 2. Main elements that form ash deposits

| Element | СаО | К2O | Na2O | MgO | SiO2 | MnO | Al2O3 | P2O5 | Fe2O3 | С |
|---------|-----|-----|------|-----|------|-----|-------|------|-------|---|
| Content, % | 37.18 | 11.00 | 7.34 | 5.01 | 3.14 | 2.45 | 1.64 | 14.16 | 0.75 | 4.22 |

During energy survey, wastes from plywood production were supplied to the furnace of the boiler, which included bark, veneer shorts, chip plywood, WSD and sawdust. The burning fuel mixture had a high coefficient of uniformity of particle-size distribution (mean polydispersity index $n = 0.655$, and the coefficient characterizing the size of the composition $b = 3.258 \cdot 10^{-3}$). The moisture content of wood fuel (Table 1) was lower than the design value ($W_t = 30.0-32.0\%$) which is associated with a high content of small explosive fractions (WSD and sawdust from line of cutting). The mass fraction of particles smaller than 2 mm was more than 32% as shown in Fig. 2.

![Figure 2](image)

**Figure 2.** Fractional residues characterizing the particle size distribution of the fuel mixture and its two explosive components

The results of balance experiments have shown that the design of the boiler and the automatic control system of its operations ensure a high rate of combustion of carbon monoxide with the concentration not exceeding 35 mg/Nm³ at $K_{O2} = 6\%$.

The water temperature at the inlet of the economizer was stable (Table 1) which made it possible to ensure its degassing and sufficiently deep cooling of the flue gases.

The design of the air heater allowed to provide heating of the primary air to 79-81 °C. The combustion products were cooled to 151-154 °C when passing through the air heater. The secondary air temperature was 30-32 °C. These factors ensured a low level of combustion chamber lining temperature, the temperature of which did not exceed 920 °C.

Investigations of the particle size distribution of combustion residues, carried out in accordance with [4], showed that fly ash, taken from the ash collector and air heater, has a high polydispersity index of the particle size distribution ($n = 0.405$) and a very finely dispersed composition ($b = 0.207$). Particles with a size smaller than 45 μm predominate, the mass fraction of which exceeds 64%. This particle size distribution of fly ash indirectly indicates a high ash collectors efficiency. Studies of the particle size distribution of combustible components in fly ash showed that particles with a size of 1000 μm or more, as illustrated in Fig. 3(a), have a maximum content of combustible components. However, their mass fraction in fly ash is low, therefore the content of combustible components in particles $d_p<45$ μm, as shown in Fig. 3(b), has a decisive influence on combustible loss.
The resistance of the gas path of the boiler depends on its load, the fraction of flue gas recirculation and the characteristics of the burning fuel. During balance experiments, the total resistance of the boiler with the steam generator, economizer, ash collector and air heater varied in the range 3.87-3.92 kPa. In this case, the resistance of the boiler components was: 1.02-1.09 - furnace with steam generators; 0.60-0.65 - economizer; 1.29-1.30 - ash collector; 0.88-0.91 kPa - air heater.

The ash and slag collected from the combustion chamber have a uniformity particle-size distribution \( n = 0.537 \), with particles of 250 \( \mu \)m or more dominating in combusting residues, whose mass fraction was 55.56%.

The method of external filtering [5] was used to determine the flue gas dust content and the efficiency of the ash collector. Flow metering and control of taken combustion products was carried out using the aspiration device «OP-442 TC». The results of measurements of the velocity profile and the concentrations of the solid particles in the flue gases to the economizer showed that the structure of the gas stream in this measuring section does not allow obtaining objective results. Accordingly, a mass method of fuel and ash balance should be used to determine the flue gases removal efficiency from particulates.

The structure of the gas stream in the measuring section of the flue before the chimney allows obtaining objective data on the concentration of the solid particles in the combustion products. The average value of particulates concentration in combustion products in this flue was 111.8 mg/Nm\(^3\) with a boiler load of 96% of the based.

Investigation of solid particles contained in combustion products upstream of chimney, performed with a scanning electron microscope Vega 3 Tescan, showed that particles smaller than 1 \( \mu \)m predominate as illustrated in Fig. 4. The length of most particles exceeds the equivalent diameter. The performed investigations made it possible to determine the values of the emissions of solid particles, which amounted to 57.08-62.84 g/GJ. At the same time, soot particles emission factors varied in the range 7.99-8.80 g/GJ.
Figure 4. Quantitative characteristics of solid particles emitted into the environment, depending on their size (a) and shape (b).

Analysis of the thermal conditions of the boiler showed that the heat losses with the stack gases had moderate values, which is explained by their low temperature. The design of the reciprocating grate and the cooling system of its frame ensured the absence of slag adhesions and reliable operation of the slag removal unit at high rate of combustion in ash residues (content of combustibles in slag 9.0%, fly ash 15.8%). Losses due to temperature of bottom ash did not exceed 0.02%.

A relative method was used [6] to determine the external heat loss. The enclosing surfaces were segmented into sections, each of which measured average temperatures using a pyrometer. Based on the results of measurements of average temperatures in 810 sections, heat transfer coefficients were calculated, and then external heat losses were calculated. Sufficient quality of firing and heat insulating materials allowed to ensure a low level of this loss (Table 1), which was 0.54 % for the based load of the boiler.

4. Conclusions
The launch of the steam boiler PRD 22000 ensured a fairly economic energy use of the fuel mixture consists of chip plywood, pitch bark, veneer, WSD, sawdust of the plywood processing. The gross efficiency of the boiler unit in the investigated range of loads was 89.40 - 90.26%. The specific reference fuel consumption for the generation of 1 GJ was 37.78-38.14 kg.

The design of the main and auxiliary equipment of the boiler ensured its work with high ecological indicators. Concentrations of harmful substances, corrected to an excess air factor of 1.4, were: carbon monoxide 33-35; nitrogen oxides 142-154; solid particles 106.5-113.8 mg/Nm³. The implementation of the project on the energy use of plywood waste for the generation of thermal energy has significantly reduced environmental pollution, and ensured full technological needs of the plant in the process steam.

The present research showed that the boiler PRD-22000 has reserves for further improvement of technical, economic and ecological performance. One of the ways to increase the period of operation
between cleaning the heating surfaces of the boiler and to increase its energy and ecological performance is the refusal to use sawdust of the plywood processing and WSD in the burned fuel mixture. These fine fractions should be used for the production of fuel briquettes. Nowadays experience has been gained in the industrial production of briquettes and their use for low-power heat generators. The results of fuel tests showed that these briquettes have sufficiently high thermotechnical characteristics ($W'_t = 5.05\%$, $A'_t = 0.83\%$, $Q'_i = 17.07$ MJ/kg, density $0.974$ t/m$^3$) and provide efficient operation of low-power heat generators.

**Acknowledgment**

The authors are grateful to Esseev Marat Kanalbekovich for assistance in performing studies of solid particles on a scanning electron microscope.

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