Energy use of plywood by-products

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Abstract. An effective way of using plywood by-products is burning to obtain energy required in the technological cycle of the production. The PRD 22000 boiler was operated on fuel mixture consisting of crushed plywood waste, birch bark, dry and wet veneer shorts, wood sanding dust and sawdust from line of plywood cutting, sufficiently high energy and environmental performances were obtained. However, periods of the boiler operation between shutdowns for cleaning of heating surfaces were short. Studies have shown that crushed plywood waste is the strongest contaminant of combusted fuel mixture since of its ash contains a very high amount of CaO, Na₂O, K₂O which cause the incrustation on heating surfaces. Wood sanding dust and sawdust from line of plywood cutting, which contain particles of abrasive material and binder resins used to fix it on sanding belts, as well as particles of glue used in the production of plywood occupy the second position in terms of pollution level. The exclusion of these components from combusted fuel mixture allows to multiply periods of boiler operation between shutdowns for cleaning of heating surfaces in six times.

1. Introduction

Plywood production is characterized by a relatively low final yield of the finished products: more than half of processed wood turns into waste [1-2]. Therefore, energy use of waste is the one of the most important ways to reduce finished product cost and increase plywood production effectiveness. Furthermore, it allows you to eliminate landfills and dumps, preserve fertile soils, etc. An effective way of using plywood by-products is burning to obtain energy required in the technological cycle of the production [3-8]. In 2015, the PRD 22000 boiler from the Austrian company Polytechnik Luft- und Feuerungstechnik GmbH was mounted and put into operation at Arkhangelsk plywood factory to reduce product costs, reduce the impact of environmental concerns on the sustainability and stability of the company’s development, as well as reduce emissions into the atmosphere.

The boiler unit is installed in an individual industrial boiler house and is equipped with an automatic control system for all technological processes. This boiler produces saturated steam at a working pressure of 1.2 MPa, its nominal capacity 22 MW. To produce steam it was decided to burn the fuel mixture consisting of crushed plywood waste, birch bark, dry and wet veneer shorts, wood sanding dust and sawdust from line of plywood cutting. 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. The separation of the finely dispersed fraction from the transporting agent was carried out in bag filters, after which it was sent to the boiler fuel path. At the same time, a pressing of the channel providing the supply of a finely dispersed fraction was periodically observed,
and there was no possibility of its uniform entry into the fuel path. The process of agglomeration and clumping for the finely dispersed fraction was observed.

2. Materials and methods

An energy survey of the boiler house was performed for a comprehensive assessment of operational efficiency of the installed equipment. During the survey, the following were carried out: external and internal inspection of boiler elements; calibration of flues, analysis of the operation of the main and auxiliary equipment; balance experiments; analysis of energy and environmental performance of the boiler unit.

The energy survey was carried out in accordance with the requirements for industrial and operational tests of the third category of complexity [9-11]. Testo-350 XL was used to study the composition of combustion products. A Pitot tube and a micromanometer of the precision instrument Testo-435 were used to determine flue gas flow rates. The results of the velocity field study were used to determine the concentration of particulate matter in flue gases. For this purpose, an external filtration method was applied, for the implementation of which an aspiration unit "OP-442 TC", a dust intake probe, a filter holder were used.

A Zeiss SIGMA VP (Carl Zeiss) scanning electron microscope was used to study the structure, size, shape and quantitative composition of particulate matter captured from the flue gas stream.

Thermal analysis of fuel wood was carried out with apparatus of complex thermal analysis lab and IKA C 2000 basic Version 2 calorimeter with LOIP FT-216-25 cryothermostat.

The elemental composition of the fuel mixture and the focal residues were determined using an XRF-1800 X-ray fluorescence spectrometer and a Euro EA-3000 analyzer.

The study of the grain size distribution of fuel and focal residues was carried out using AS 200 Control and “029” analyzers [3].

A relative method was used to determine the external heat loss [9]. Fuel consumption was determined by the inverse heat balance equation. Processing of experimental data was carried out using a multimodule software and methodological complex [3].

3. Results

Combusted fuel mixture had a high degree of polydispersity of grain size distribution (average polydispersity coefficient \( n = 0.655 \) and coefficient of fineness \( b = 3.258 \times 10^{-3} \)). Moisture of fuel wood (table 1) was lower than the design which is due to the high content of explosive fractions in the mixture.

To ensure effective burnout of the combustible components of the fuel mixture, an intermediate arch is installed in the furnace (figure 1), which divides it into a combustion chamber and an afterburning chamber connected by a throat located at the front wall of the furnace. The combustion chamber is equipped with devices for fuel supply, zoned primary air and recirculation gases distribution under reciprocating grate. Under each of the four zones on the one side supplies primary air after the air heater, and on the other side, recirculation gases taken from the flue after the main exhauster. The primary air is supplied by individual fans, and the recirculation gases are supplied by a separate fan.

Secondary air and recirculation gases are supplied to the volume of the combustion chamber above the grate through nozzles located on the side walls. The nozzles for the supply of recirculation gases are located horizontally above the first, second and third zones of the grate and are directed opposite, with part of the nozzles located in one horizontal plane, and the other part in one inclined plane in the direction of fuel movement. Part of the secondary air supply nozzles is located in an inclined plane in the direction of fuel movement along the grate, above the recirculation gas inlet nozzles, and has a counter layout.

The other part of the secondary air nozzles is located horizontally in two rows with a staggered layout in the area of the furnace throat and is directed counter. These nozzles supply air to complete the combustion process and minimize the formation of nitrogen oxides. The secondary air is supplied
using an individual fan, and the recirculation gases are supplied to the chamber volume above the grate using a separate fan. The total proportion of recirculation gases was 0.35-0.40 with the boiler capacity of 89-96% of the nominal. All fans and exhausters are equipped with a frequency control system.

Table 1. Results of tests of the boiler PRD-22000.

| Value (dimension)                              | Test No.1 | Test No.3 |
|------------------------------------------------|-----------|-----------|
| Steam capacity (t/h)                           | 31.0      | 33.3      |
| Working pressure of saturated steam (MPa)      | 1.15      | 1.15      |
| Feed water temperature (°C)                    | 106.7     | 106.5     |
| Working pressure of feed water (MPa)           | 1.53      | 1.53      |
| Fuel moisture, Wf (%)                          | 26.74     | 26.74     |
| Fuel ash content, Af (%)                       | 0.45      | 0.45      |
| Low calorific value, Qf (MJ/kg)                | 13.22     | 13.22     |
| Primary air temperature (°C)                   | 80.0      | 80.0      |
| Gas temperature at economizer inlet / outlet (°C) | 244/168  | 231/168  |
| Gas temperature at air heater inlet / outlet (°C) | 165/151  | 164/150  |
| Air-fuel ratio in flue gas                     |           |           |
| Heat loss with:                                | flue gas (%) | 9.49 | 9.87 |
| incomplete combustion (%)                      | 0.01      | 0.01      |
| combustibles (%)                               | 0.13      | 0.14      |
| external heat (%)                              | 0.61      | 0.56      |
| Gross efficiency (%)                           | 89.75     | 89.40     |
| Total fuel consumption (t/h)                   | 6.121     | 6.593     |
| Emission NOx (mg/MJ)                           | 64        | 67        |
| Emission CO (mg/MJ)                            | 12        | 11        |
| Emission of particulate matter (mg/MJ)         | 62.84     | 60.83     |

After the furnace throat the combustion products enter the afterburning chamber, where they move towards the rear wall of the combustion chamber. The useful flow area for the passage of gases increases, and the speed of flue gases decreases. In the area of the rear wall, the flue gases make a turn of more than 90 degrees. Reducing the flue gas velocity and the presence of their reversal include gravity-inertial separation mechanisms, which makes it possible to separate the largest solid particles from the gas stream and remove them from the volume of the combustion chamber into a dry ash removal system. After the turn, the flue gases move vertically upwards, are divided into two streams and enter the turning gas chambers, where after a 90-degree turn they are moved into the firetubes of steam generators. Two-way gas steam generators are located horizontally, parallel to the longitudinal axis of the boiler. During the energy survey, the average gas velocity during the first move was 16.4-17.0 m/s, and during the second move, it increased to 17.5-18.2 m/s. The temperature of saturated steam at the outlet of the steam generators was 189-191°C, it had values close to the standard. The temperature of the gases at the inlet to the steam generators varied in the range of 850-868°C.

Walls of the furnace chamber are made of refractory fireclay brickwork. The maximum temperature of flue gases at the entrance to the turning gas chambers of steam generators is 950°C.

A three-stage fuel combustion scheme is implemented in the combustion chamber. In the studied range of loads, the heat liberation rate of the fuel burning area was 0.746–0.802 MW/m². The results of balance experiments have shown that the design of the boiler unit and the automatic control system provide a high completeness of carbon monoxide burnout.
The velocity of gases in the pipes of the water economizer was 15.8–16.4 m/s. Flue gases after the economizer enter the multicyclone, where they are cleaned of particulate matter. The purified gas is sent to the recuperative air heater, in which it provides heating of the primary air, making two passes (table 1).

An analysis of the operating conditions of the boiler unit showed that heat losses with flue gases were moderate (table 1), which is explained by the low temperature of flue gases. The design of the reciprocating grate and the cooling system of its frame ensured the absence of clinker adhesion and reliable operation of the slag removal unit. Losses with the sensible heat of the slag did not exceed 0.02%.

A relative method was used to determine the external heat loss [9-10], while the enclosing structures were divided into separate sections, in each of which the average temperatures were measured using a pyrometer. Satisfactory quality of lining and heat-insulating materials made it possible to ensure a low level of this loss (table 1).

4. Discussion
The boiler service experience has shown that its combustion chamber is very sensitive to changes in the grain-size distribution and thermal characteristics of the combusted fuel mixture. Period of boiler operation between shutdowns for cleaning was one month. To maintain an acceptable temperature level in the combustion chamber, it was necessary to supply a large volume of recirculation gases, which increased the gas velocities and the removal of the solid phase into the fire tubes of steam generators and, accordingly, their pollution. Even with a high proportion of recirculation gases, the temperature level in the combustion and afterburning chambers was too high, which reduced the
service life of the refractory fireclay lining, especially the ceiling part in the afterburning chamber and the lower inclined wall of the intermediate arch in the combustion chamber. At the same time, during operation, even the collapse of the fireclay lining of the ceiling wall of the afterburning chamber was observed, which caused damage to the grates and the structure of the reciprocating grate and the need for lengthy restoration work. These negative factors led to a comprehensive decrease in the efficiency of the boiler unit, to an increase in financial costs and the duration of repair work.

To identify the possible reasons for the formation of bonded deposits at the inlet to the fire tubes, samples were taken and their composition was analyzed using an EDX-8000 X-ray fluorescence spectrometer and a Euro EA-3000 analyzer. A high content of alkali metal oxides leads to the formation of bonded deposits on the inner surfaces of the fire tubes [10]. The presence of particles of abrasive material in wood sanding dust and binder resins used to fix it on sanding belts, also contributes to the intensification of the contamination of the fire tubes and the increased content of aluminum oxide. The presence of oxides of manganese, titanium, and chromium in the studied deposits may be the result of burnout of the grate, made of chromium-alloyed steel casting and located in the most heat-stressed zones of the reciprocating grate.

One of the ways to increase the period of operation between cleanings of heating surfaces is to avoid introducing sawdust from the plywood cutting line and wood sanding dust into the combustible fuel mixture. These wastes began to be used to produce fuel briquettes "Nestro".

The addition of briquettes to the fuel mixture did not solve the problem of effective utilization of wood sanding dust and sawdust from the plywood cutting line because of their cylindrical shape caused rolling along the reciprocating grate. They quickly overcame the combustion zones, not completely thermally decomposing and burning out, and ended up in the ash and slag removal system, where they continued to burn, which led to increased losses with mechanical incomplete combustion and created a fire hazard.

At the next stage, equipment to produce RUF eurobriquettes was purchased and installed. Since then, the plywood plant began producing prismatic briquettes, which found an increased demand among local entrepreneurs and the population, which eliminated the need for their energy use in the PRD 22000 boiler unit. Thus, the problem of utilization fine fraction waste was solved. The periods of the boiler operation between shutdowns for cleaning of heating surfaces with the exclusion of sawdust from the plywood cutting line and the wood sanding dust from the fuel mixture increased to two months. However, the main factor hindering a further increase in the periods between boiler cleanings was the supply of crushed plywood wastes containing resins to the fuel mixture.

To elucidate the reasons for the high intensity of contamination of the heating surfaces of the boiler unit, the elemental composition of crushed plywood and ash formed during their combustion were studied using an EDX-8000 spectrometer and an Euro EA-3000 analyzer (table 2).

| Element | Crushed plywood | Ash | Element | Crushed plywood | Ash |
|---------|-----------------|-----|---------|-----------------|-----|
| CaO     | 0.777           | 65.0| ZnO     | 0.003           | 0.026|
| Fe₂O₃   | 0.025           | 1.02| CuO     | 0.001           | 0.043|
| SO₃     | 0.042           | 0.261| MnO     | 0.009           | 0.710|
| SiO₂    | 0.046           | 4.98| Cr₂O₃   | 0.002           | 0.034|
| P₂O₅    | 0.021           | 0.643| Cl      | 0.077           | 0.556|
| NiO     | 0.001           | 0.012| Na₂O    | 0.521           | 15.90|
| K₂O     | 0.071           | 2.05| O       | 44.80           | 0.939|
| Al₂O₃   | 0.015           | 0.735| N       | 1.51            | 0.189|
| MgO     | 0.035           | 2.88| C       | 46.5            | 3.36 |
| SrO     | 0.002           | 0.134| H       | 5.55            | 0.471|
The obtained results showed that crushed plywood is the strongest contaminant in the combusted fuel mixture, since the content of CaO in its ash is five times higher than the threshold value [10], and the content of alkali metal oxides Na₂O + K₂O = 17.95%, giving bonded deposits on heating surfaces, almost 5.8 times higher than the limit values.

The exclusion of this component from the fuel mixture made it possible to ensure the stable operation of the boiler, while its periods between shutdowns for cleaning increased to six months. The crushed plywood waste has found its energy use at small-scale power facilities equipped with water-tube boilers with grate firing when it is added to the wood chips. Thermal analysis showed that it has sufficiently high energy properties (Wₜᵢ = 5.00%; Aᵢ = 1.49%; Qᵢ = 17.71 MJ/kg; dry and ash free volatile yield is 77.00%).

5. Conclusion

The commissioning of the PRD 22000 steam boiler unit ensured the energy use of a fuel mixture consisting of crushed plywood waste, birch bark, dry and wet veneer shorts, wood sanding dust and sawdust from line of plywood cutting. The gross efficiency of the boiler unit in the studied load range was 89.40-90.26%, and the specific consumption of reference fuel to produce 1 GJ was 37.78-38.14 kg. Emissions of harmful substances: carbon monoxide 11.0-12.0; nitrogen oxides 62.0-67.0; particulate matter 57.1-62.8, including soot particles 7.99-8.80 mg/MJ. However, the combustion of this fuel mixture caused intense contamination of the heating surfaces, which limited the period of boiler operation between shutdowns for cleaning to one month and led to a comprehensive decrease in the efficiency of the boiler unit, as well as a significant increase in operating and repair costs.

Studies have shown that crushed plywood waste is the strongest contaminant of combusted fuel mixture since its ash contains a very high amount of CaO, Na₂O, K₂O which cause the incrustation on heating surfaces. Wood sanding dust and sawdust from line of plywood cutting, which contain particles of abrasive material and binder resins used to fix it on sanding belts, as well as particles of glue used in the production of plywood occupy the second position in terms of pollution level. The exclusion of these components from combusted fuel mixture allows to multiply periods of boiler operation between shutdowns for cleaning in six times. The launch of the production of fuel briquettes from fine fraction wastes of plywood factory allowed us to obtain fuel that has sufficiently high energy properties (Wᵢ = 5.0–5.8%; Aᵢ = 0.83%; Qᵢ = 17.0–17.1 MJ/kg; density 0.97–0.99 t/m³) and steady demand among local entrepreneurs and the population and ensures the efficient operation of low-power heat generators. The use of crushed plywood waste as an additive to fuel chips for water-tube boilers with grate firing allowed for its effective use in small-scale energy.

The implementation of the project on the energy use of by-products of plywood production for the generation of thermal energy has significantly reduced environmental pollution, as well as fully met the needs of the plant in saturated steam.

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