Furnace chamber heat exchange peculiarities in using different types of coal

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Abstract. The paper considers the types of heat transfer in the furnace chamber and ash residue values influence on the heat released and received in the furnace. The influence of different grades of coal (Kamyshanskij, Taldinskij and Ekibastuzkij deposits) with ash residue value from 16.4 to 43 % on the furnace combustion heat was analyzed. The ash residue value influence on the value of the heat received in the combustion chamber, which is the boiler efficiency defining characteristic, is considered. The graphical dependence of the heat amount received in the combustion chamber on the ash residue for the different types of solid fuel is shown.

Keywords: solid fuel, boiler, ash residue, combustion heat.

1. Introduction
The fuel burning flaring method, i.e. burning the fuel supplied from the burner devices in the free space of the furnace chamber limited by the shielded insulating walls, as a flame inside the furnace volume is widely used in the high-powered boilers [1].
The choice of coals for combustion at Omsk CHPP should be considered taking into account the possibility of burning other fuel grades; reliability of the boiler unit run on the new fuel; maintenance safety of the existing fuel feed path when using the given fuel; efficiency of the flue gas treated by the gas facilities existing system. In the present study, the coal choice determining factor is the combustion chamber operating efficiency.
When addressing this issue, the nearby regions to supply Omsk power grid heat sources with coal, i.e. Kuznetskij, Ekibastuzkij coal basins are under consideration.

2. Problem statement
Depending on the burned fuel type, the furnace walls perceive from 40 to 50 % of the total heat amount given to the boiler operating environment and other heating surfaces. The solid fuel combustion efficiency in the chamber furnaces is determined by the heat perceived in the combustion chamber, which depends on the net calorific value Q_N and heat amount perceived in the combustion chamber Q_R. The research objective is to define the fuel calorific value, heat amount perceived in the

combustion chamber and combustion products volume taking into account the coal combustion peculiarities of Kuznetskij, Ekibastuzkij deposits which are different in chemical composition [2].

3. Theory

One of the main characteristics of any fuel type is the calorific value, i.e. the heat amount to be obtained by the complete combustion of the fuel mass or volume unit. This heat is determined by the fuel chemical composition. Fuel combustion processes, radiation and convective heat exchange between the filling medium and heating surfaces simultaneously occur in the combustion chamber.

The radiation source in the combustion chambers during burning is the fire bed surface, volatile substances combustion flame, triatomic fuel combustion products CO_2, SO_2 and H_2O [3].

When burning the solid fuel dust by flaring, the flame cores formed close to the fuel particles surfaces as a result of theflame volatile substances combustion, close to the hot coke and ash particles, as well as triatomic fuel combustion products are the radiation sources

The radiation concentration and thickness values determine the radiation of triatomic gases filling the combustion chamber volume. Triatomic gases radiation is from 20 to 30 % of the total radiation in the furnace atmosphere.

The walls thermal efficiency and furnace atmosphere intensity determine the heat absorption of the furnace walls. Increasing the furnace chamber atmosphere radiation intensity results in growing the value of the heat flux falling on the walls. The walls heat absorption reduction is achieved by reducing the walls thermal efficiency.

Heat absorption of the radiant heat absorbing surface is defined by the following formula:

$$Q_R = c_0 \cdot \left[\left(\frac{T_R}{100} \right)^4 - \left(\frac{T_S}{100} \right)^4 \right] \tag{1}$$

where T_R is the radiating surface temperature, T_S is the heat-absorbing surface temperature.

The heat amount received in the furnace chamber is calculated according to the formula:

$$Q'_R = \varphi \cdot B_c (Q_F - h'') \tag{2}$$

where $Q_F = \frac{Q_a \cdot (100 - q_3 - q_4 - q_6)}{100 - q_4} + Q_{in}$ is the useful heat dissipation in the furnace;

h'' is the enthalpy of gases at the furnace chamber outlet;

q_i is the heat loss;

Q_a is the available calorific value;

Q_{in} is the heat injected into the furnace chamber by air.

Convective heating surfaces of the steam and hot water boilers play an important role in the process of obtaining steam or hot water, as well as using the heat of combustion products leaving the furnace chamber. The convective heating surfaces efficiency largely depends on the intensity of heat transfer to water and steam by the combustion products.

Combustion products transfer the pipes outer surface heat by convection and radiation. Heat is transferred through the wall by thermal conductivity from the pipes outer surface to the inner one, and by convection from the inner surface to water and steam. Thus, the transmission of heat from combustion products to water and steam is a complex process called heat transfer.

Heat transfer and heat balance equations are used in calculating the convective heating surfaces. The calculation is performed for 1 kg of the combusted solid fuel and liquid fuel or 1 m^3 of gas under the normal conditions.

Heat transfer equation is:

$$Q = K \cdot H \cdot \frac{\Delta t}{B_c} \tag{3}$$

Heat balance equation is:

$$Q_b = \varphi (h' - h'' + \Delta\alpha \cdot h^0_{SA}) \tag{4}$$

Where K is the heat transfer coefficient related to the calculated heating surface; Δt is the temperature pressure; B_c is the calculated fuel flow rate; H is the calculated heating surface; φ is the heat storage coefficient taking into account the external cooling heat loss; h' and h'' are the combustion products enthalpies at the heating surface inlet and outlet a; I_{SA}^{0} is the heat quantity injected by the sucked air into the gas duct.

In equation (3) the heat transfer coefficient is the process calculated characteristic and is defined by the phenomena of convection, thermal conductivity and radiation. The heat amount transmitted through the wall is directly dependent on the heat transfer coefficient and temperature difference between the combustion products and heated liquid. Heating surfaces in the vicinity of the furnace chamber operate at greater temperature difference of the combustion products temperature and heat perceiving environment one. As the combustion products move along the gas path, their temperature decreases and tail heating surfaces operate at lower temperature difference. Therefore, the further the convective heating surface is located from the furnace, the larger it should be.

Equation (4) shows the heat amount released by the combustion products and transferred to water or steam through the convective heating surface.

The complete combustion products total volume equation (5):

$$V_G = V_{RO_2} + V_{N_2}^{o} + V_{H_2O} + 1.0161(\alpha_{av} - 1)V^{o} \tag{5}$$

Where V_{RO_2} is the triatomic gases volume; $V_{N_2}^{o}$ is the nitrogen volume; ;V_{H_2O} is the water vapour volume; α_{av} is the excess air coefficient, V^{o} is the theoretical air volume.

The purpose of calculating the heat transfer in the furnace chamber is to define the combustion products temperature values at the furnace chamber outlet under the given design parameters and operating conditions. Besides, the heat transfer calculation purpose can be to determine the heat perceiving surfaces areas when the target temperature at the end of the furnace chamber is provided [2-5].

The boiler unit gross efficiency (%) can be calculated using the direct balance equation.

For the steam boilers the equation has the following form:

$$\eta_{gr} = \frac{Q_{SG}}{Q_o^{a} \cdot B_{SG}} \cdot 100; \tag{6}$$

where Q_{SG} is the net power of the steam boiler; B_{SG} is the fuel consumption of the steam boiler; Q_o^{a} is the available heat.

Steam and hot water boiler efficiency is defined according to the indirect balance equation:

$$\eta_{gr} = 100 - \sum q_i, \tag{7}$$

where $\sum q_i$ is the heat losses sum.

In conducting the thermal calculation of the steam or hot water boiler, the heat balance is compiled for defining the gross efficiency and calculated fuel consumption.

4. Experimental results

Thermal calculation of the BKZ-420 boiler furnace chamber for different coal grades results in obtaining the following dependences: the net calorific value dependence on the ash residue (Fig. 1); the dependence of the heat amount received in the furnace on the ash residue (Fig. 2); the combustion products volume dependence on the ash residue (Fig. 3) for different types of coals (Kamyshanskij, Taldinskij, Ekibastuzkij).

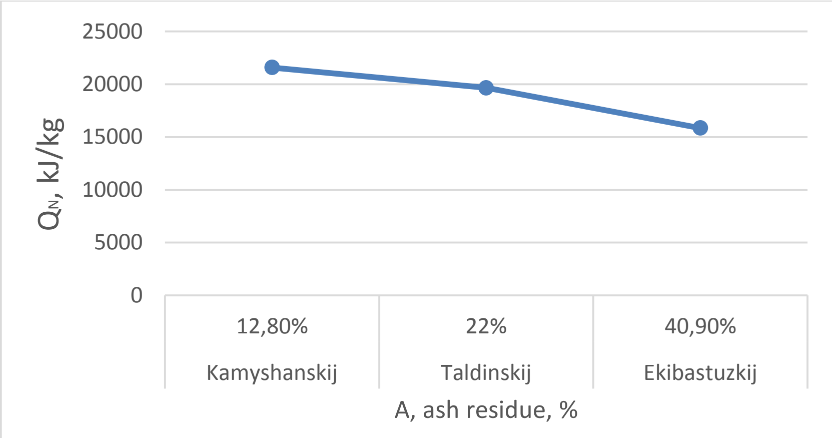

Figure 1. The net calorific value dependence on the ash residue.

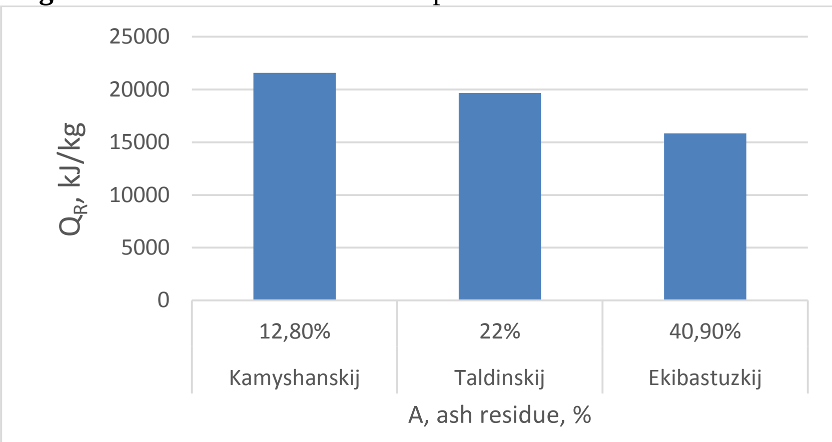

Figure 2. The dependence of the heat amount received in the furnace on the ash residue.

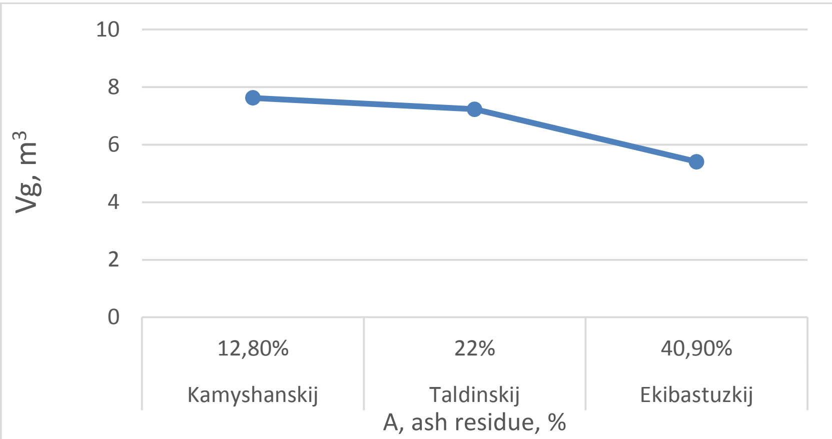

Figure 3. The combustion products volume dependence on the ash residue.

5. Results discussion

Figure 1 shows that the ash residue increase results in decreasing the net calorific value Q_N as the volatile substances yield is reduced, which value depends on the coal grade (Ekibastuzkij, Kamyshanskij, Taldinskij). Figure 2 represents that the ash residue increase leads to decreasing the value of the heat amount perceived in the furnace Q_R. This is due to the combustion temperature reduction. The combustion products volume dependence on the ash residue is shown in Fig. 3. It is observed that the ash residue increase results in the combustion products volume value decrease, as the volatile substances proportion is growing.

6. Conclusions
The calculation studies revealed the following results:

- The replacing Ekibastuzkij coal with Taldinskij or Kamyshanskij coals leads to the net calorific value increase from 15857 kJ/kg to 19665 and 21589 kJ/kg, correspondingly.
- The replacing Ekibastuzkij coal to Taldinskij or Kamyshanskij coals leads to the radiant component value increase by 7 % and 15 %, correspondingly.
- The replacing Ekibastuzkij to Taldinskij or Kamyshanskij coals leads to the combustion products volume increase by 25 % and 30 % correspondingly.

7. References
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