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INVESTIGATION OF AERODYNAMICS AND BURNING IN BOILER FURNACE БКЗ-420-140 AS APPLIED TO REPLACEMENT VARIANTS OF PROJECT FUEL

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The results of studying furnace processes in boiler furnace BKZ-420-140 of Omsk heat power plant-4 at burning project fuel in it (Ekibastuz coal) and substituting coals (Kuznetsk D and Irsha-Borodinsk coals) on the basis of mathematical models of applied program package FIRE 3D are presented. The analysis of the results obtained in three-dimension interpretation applicable to each fuel type as well as comparison of the obtained data with standard calculations is made.

Introduction

The series of unique boiler units for burning mineral carbon of Ekibastuz coal deposit is developed by domestic boiler fabrication. Boiler units BKZ-320-140 and BKZ-420-140, PK-39 for feeding units of 300 MW, P-57 for feeding units of 500 MW are referred to them. They were constructed on the basis of such coal properties as good flowability, nonexplosiveness, nonregelation, low humidity and medium heat of combustion [1]. However, this coal has specific and significant disadvantages: major mineral component and considerable abrasivity of flue ash.

Owing to toughening environmental standards in Russia on pollutant emission to environment negative sides of energy burning of Ekibastuz coal have been intensified. They along with other aspects of application pose the question on exchange of Ekibastuz coal, burning at thermal power plants of Russia, for domestic coals.

The peculiarity of selection of alternative coals to Ekibastuz one consists in the fact that all known Russian coals have less-fusing ash (more slag) and consequently, boilers for them are limited by another parameters of furnace plant construction [2]. Therefore, when exchanging Ekibastuz coal, the first-priority questions are the analysis of temperature level and slagging conditions of shielded walls of boiler unit furnace.

Taking into consideration all above-listed factors – of environmental and economic type, in 1995–1996 the program of first-priority performances in substitution of Ekibastuz coal by coals of Russian deposits was developed [3]. The carried out pilot burnings of Khakassia coal sift of DSS type in mixture with Ekibastuz coal, and also Kuznetsk coal of CC type were very laborious, rather expensive and difficult in organization aspect procedure. The up-to-date level of mathematical modeling of physical processes and development of special software allows solving such kind of problems in less expensive way of numerical investigation. Its advantage is the most obvious at necessity of engineering solutions selection from several variants for design study.

Object and aids of modeling

The numerical experiment was carried out for the boiler of E-420-140 type, which is intended for burning mineral carbon in powdered state.

The boiler is vertically-water-tube, single-drum, with natural circulation; made by T-shaped close integration with remote convection shaft (fig. 1).

Furnace chamber with solid slag-disposal has height clearances 27,3 m, width clearances 15,744 m and depth clearances 9,024 m, is completely shielded with tubes with diameter 60 mm,with wall thickness 5,5 mm, arranged in increments of 64 mm. Front and dorsal waterwalls in the lower part form sloping bottoms descents and throat on the top.

Oncoming swirl shovel-shovel burners are installed at mark 10800 mm, at one stage, six pieces per front and dorsal walls of the furnace. In this case flux is twisted by turns in three burners with left-handed rotation and in three others – with right-handed rotation. The diameter of burners is 1,032 m at external secondary air channel and 0,53 m at inside air mixture channel. Design speeds in burners mouth: of primary air is 18...20 m/s, of secondary air is 25,4 m/s.

The main characteristics of furnace operation with the use of Ekibastuz coal, which are taken as a principle of calculations are: coal consumption of the boiler – 70560 kg/h; of the burner – 5880 kg/h; grinding fineness of powdered coal by remnants on a sieve R_{90}=14,2 %; coefficient of excess air at the exit from the furnace – 1,2; air mixture temperature – 220 °C, temperature of secondary air – 370 °C.

The following coals are taken as ones, substituting designed fuel according to [1]: mineral carbon of D type of Kuznetsk basin and brown coal B2 of Irsha-Borodinsk deposit of Kansk-Achinsk basin. As these coals significantly differ from the Ekibastuz by heat engineering properties, it is necessary for them to fulfill other conditions of formation and ignition of air-fuel mixture. The aerodynamic schemes of torch structure due to interaction of uniflow streams in furnace volume typical for burning of highly reacting coal were examined. The scheme at which the minimal structural changes of the furnace are achieved was accepted (fig. 2).

In this case the burners remain at prior breasts, their vane swirlers are demonstrated, owing to which they become uniflow. Furnace volume is divided across the width for convenience into two parts, in each of which burners axes are pointed tangentially to a conventional circle in the center with diameter 1000 mm (fig. 2, *b*). As a result

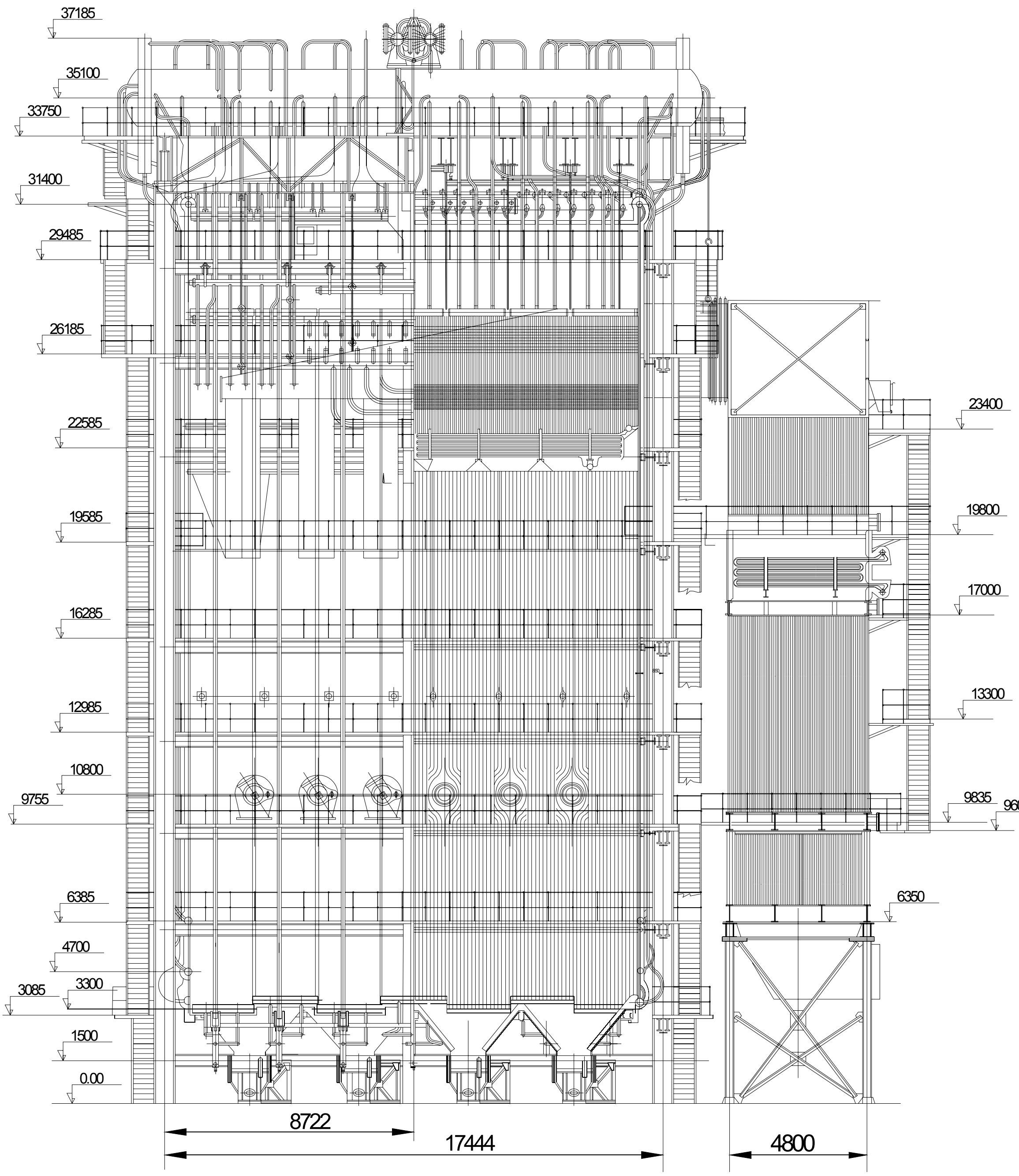
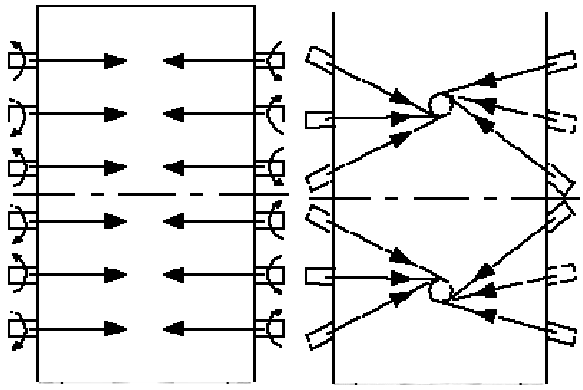


Fig. 1. *Front view and cross section of boiler BKZ-420-140*

of uniflow streams interaction a symmetric two-swirling structure of a torch with reverse swirls twist is formed.

To determine throttling and balance characteristics at sabstitutional coals burning thermal designs of the furnace per normal load by standard method [4] are carried out. The results of these designs are used as the initial data and parameters of comparison at numerical simulation. Grinding fineness of powdered coal is taken according to standard recommendations: for Irsha-Borodinsk coal is R_{90}=42 %, for Kuznetsk coal is R_{90}=25 %. Correspondingly, the outflow velocities values of primary and secondary air streams amounted: in the first case it is 20 and 28 m/s, in the second case it is 20 and 42 m/s.

The investigations of furnace aerodynamics, burning and heat-exchanging are carried out by using the applied program package FIRE 3D, which allows carrying out variant investigations on the basis of mathematical models and analyzing the obtained results in schematic view [5, 6]. The visualization is possible in two- and three dimensional variants, and any X, Y and Z sections may be determined for representation of furnace medium inner structure and any results of calculations of several researched processes may be entered and simultaneously the data on more than thirty parameters may be obtained.



a b

Fig. 2. *The scheme of burners arrangement (in plan) and directions of resultant vectors of burners streams in the furnace at burning: a) Ekibastuz coal; b) substitutional coals*

The analysis of the results

The examples of visualization of modeling processes results in the furnace are presented in fig. 3–5.

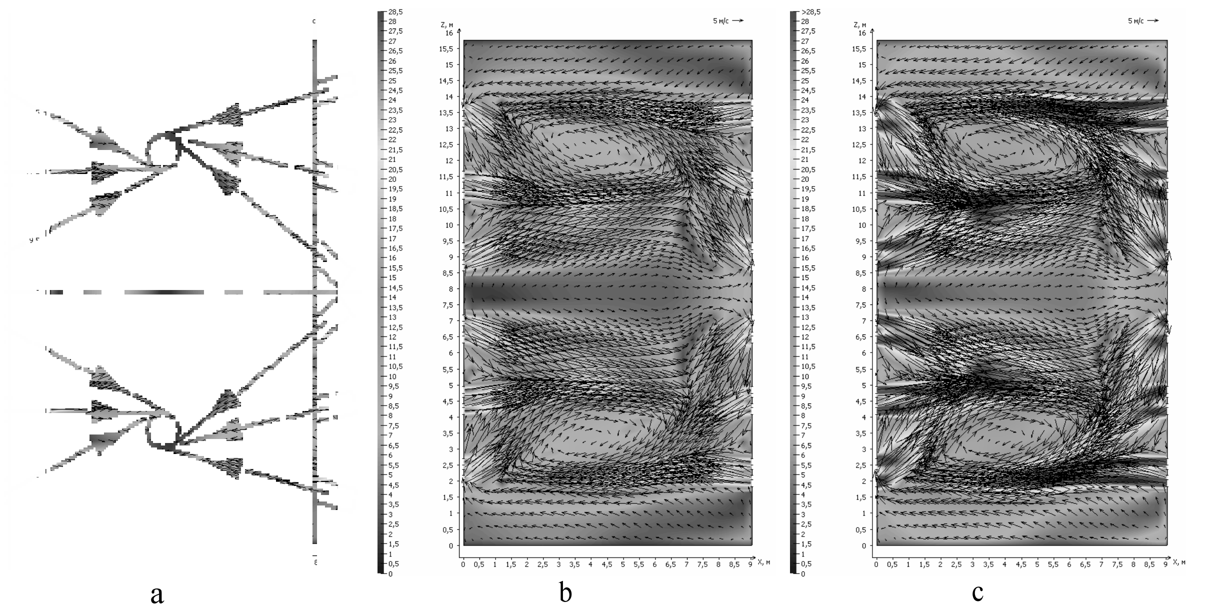
Aerodynamic structure of flows in active combustion zone (fig. 3) shows that burners layout drawing investigating for conversion to nondesigned fuel really reproduces two swirls, expanded in depth of the furnace, forming vast recycling zones near to its longitudinal axis and cheeks. The consequence of the given aerodynamics is temperature distribution in furnace volume, shown for one horizontal and one vertical section in fig. 4.

It is possible to see significant difference in conditions of burning Ekibastuz coal by existing layout drawing of burners and burning substitutional coals by investigated scheme, and in the latter case – between brown coal and mineral carbon burning.

So, Ekibastuz coal burning at oncoming integration of swirl burners (fig. 4), is characterized by relatively equal distribution of the torch in horizontal section in active combustion zone. Local values of temperature here do not exceed 1350 K in interburner gaps and straight in the core of burning in zones of intensive reaction of air-fuel mixture, almost at the level of burners axes, achieve maximal value 1770 K. As a result of collisional interaction of two rows of burner streams the bounds of combustion zone are appreciably vertically displaced in furnace volume: upward – to the level of midway between the burners and furnace throat, downwards – to the middle of height of slopping bottom. However, in upper, outlet volume of the furnace temperature does not exceed 1350 K.

Torch distribution in the furnace at two-swirling integration of uniflow burners develops absolutely another pattern of temperature fields (fig. 4, *b* and *c*). In horizontal plane high-temperature region is extended in diagonal directions and the volume, occupied by swirls as such, is characterized by rather steady temperature field that indicates the presence of conditions for intensive mixing of fuel with air and burning-out. However, as a result of differences in heat engineering properties of brown coal and mineral carbon at the same aerodynamic scheme of burning there is different temperature level and parameter of high temperature zone distribution both across section and throughout the height of combustion chamber.

Burning of brown coal (fig. 4, *b*) increases temperature in the range from 1000 to 1400 K in peripheral part of volume of active combustion zone and in swirls immediately – from 1480 to 1687 K. Core of burning is arranged throughout the height of the furnace with a little excess of the level of burner belt and develops the most steady specific thermal load to the furnace shields among the examined variants. The sequence of this is the most steady temperature field and their lowest local values in upper, outlet volume of the furnace – not more than 1420 K.



a b c

Fig. 3. *Aerodymanics of combustion chamber of boiler BKZ-420-140 in a horizontal section at mark 10800 mm. Coal: a) Ekibastuz; b) Irsha-Borodinsk; c) Kuznetsk*

The given visual pattern of combustion processes characterizes also mineral carbon burning (fig. 4, *c*), with the difference, that in all parts of the furnace higher temperature develops at local maximum 2000 K in the area of intensive swirl interaction. The important difference is also in the fact that the core of burning has much larger sizes and significant displacement upwards. As a result of this the high temperature region occupies nearly the whole space over the burner belt and even partially extends into the furnace throat. Of course, this peculiarity influences also the temperature rising in upper, outlet volume of the furnace – here local values achieve approximately 1500 K.

Modeling of interaction of furnace medium solid phase with enclosing surfaces of the furnace allowed de-

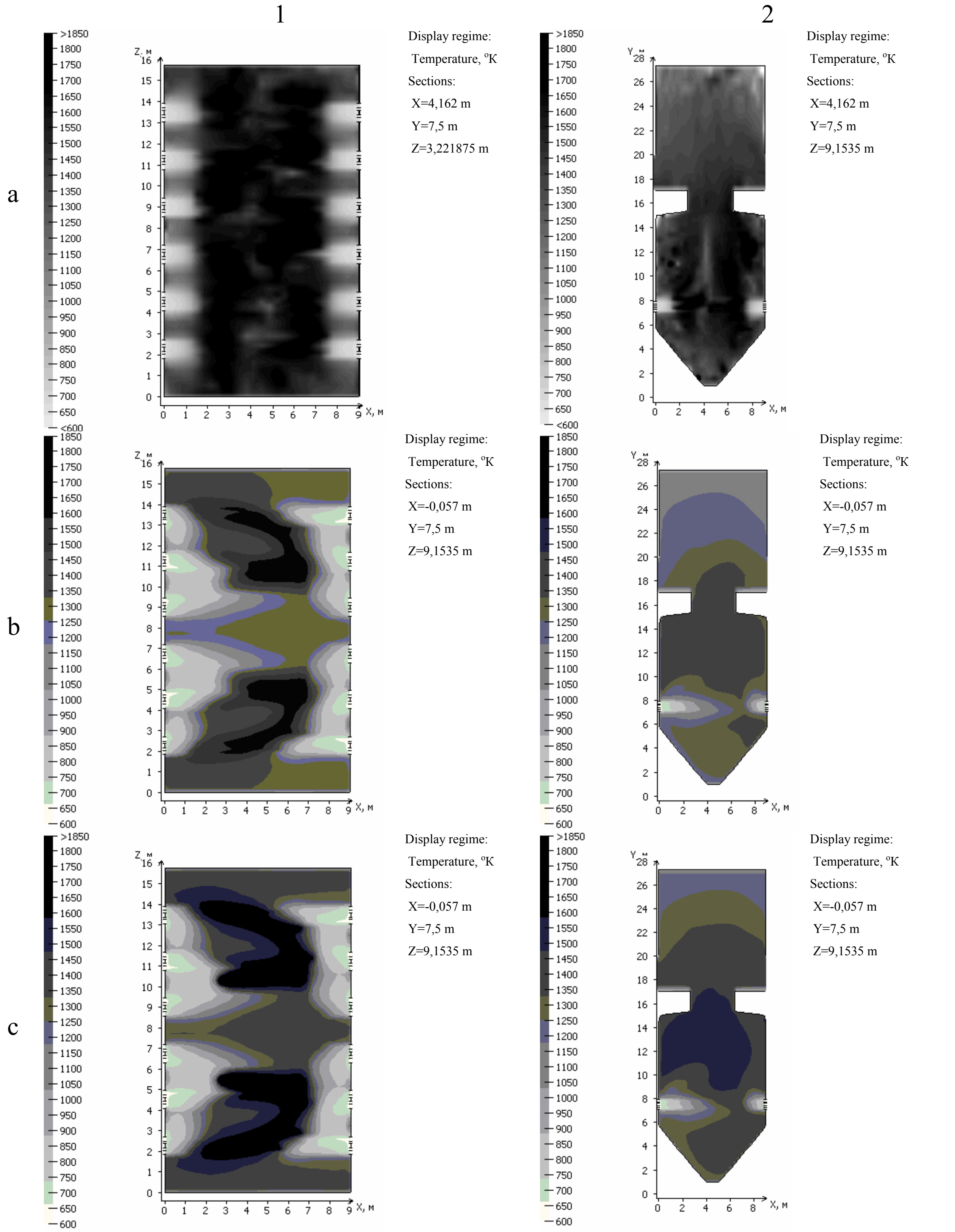
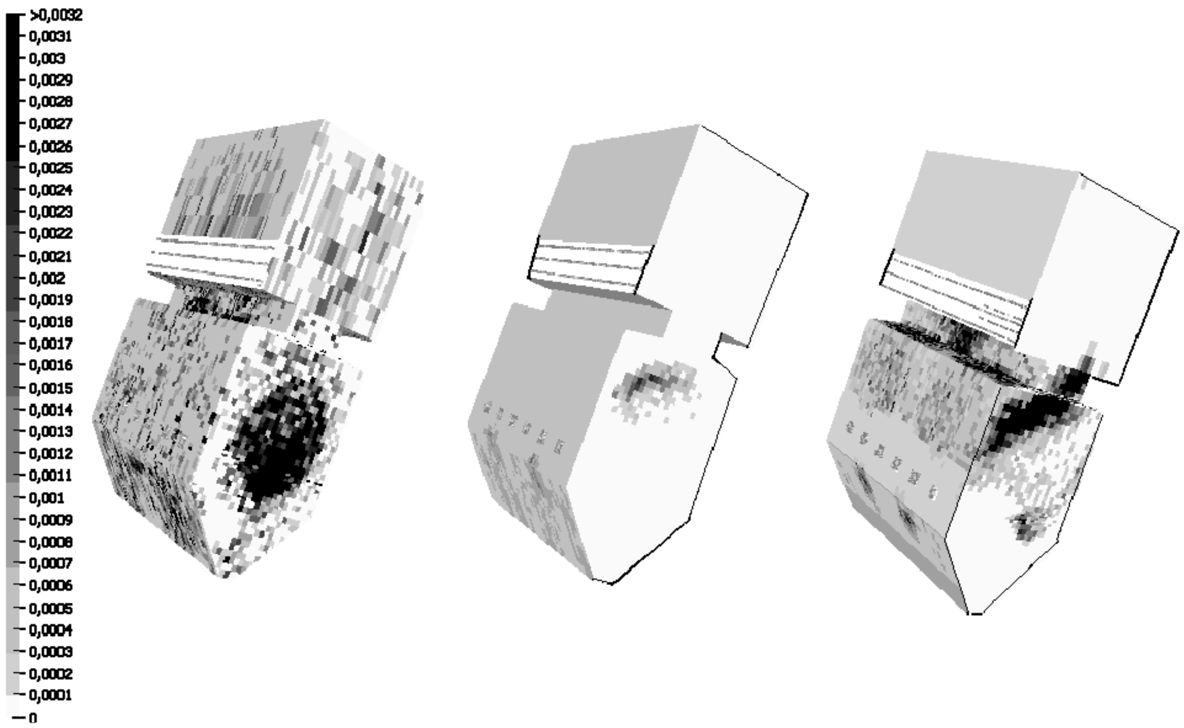


Fig. 4. *Temperature distribution in combustion chamber of the boiler: 1) in horizontal section along burners axis; 2) in vertical section along longitudinal axis of the furnace; a, b, c, are correspondingly coals: Ekibastuz, Irsha-Borodinsk, Kuznetsk*



a b c

Fig. 5. *Distribution of particles impingement intensity to the furnace shields at burning a) Ekibastuz; b) Irsha-Borodinsk; c) Kuznetsk coals*

fining the most probable zones of particles impingement on heat exchanging shields (fig. 5).

In all reserched variants of one of the typical solid phase contact zones with enclosing surfaces of the furnace are slopping bottom inclines where the main part of ash catching into slag is formed. It is possible to make quantitative assessments of slag catching coefficient and then the other components of ash balance, for example, dustiness of outgoing furnace gases according to the particle impingement intensity in slopping bottom.

Zones of particles impingement, showed on vertical shields, allow developing other peculiarities of furnace operation taking in consideration known properties of inorganic component of coals. So, at Ekibastuz coal burning (fig. 5, *a*) the most probable processes are general abrasive wear of water walls tubes and ashing up of horizontal parts in the area of throat. The most intensive particles impingement is typical for side waterwalls at the level of burner belt as height mark increasing its intensity decreases. Taking in consideration the fact that high-temperature medium here is particularly close to the shield at periodic supply of batches of coal with increase admixture of iron-containing components the conditions for alternation of processes of ash erosion and tubes slagging are created.

Comparatively reliable furnace operation according to slagging conditions is forecasted for the variant with burning Irsha-Borodinsk coal, which modeling shows the least marked sites of particles interaction with shields, and only on sidewalls (fig. 5, *b*). The most intensive shields slagging should be expected for the variant with burning Kuznetsk coal, as impingement of the particles all around the periphery of the walls of furnace bottom practically from the burner belt to the throat is stated by modeling (fig. 5, *c*).

Average temperature at horizontal sections in the furnace is shown in fig. 6 depending on change of altitude of the section.

Temperature change in the furnace of studied boiler unit at burning of Ekibastuz coal (curve 1) occurs in the following way (fig. 6). In the bottom of the furnace, approximately on the level of sloping bottom center, temperature value is 1100 °C. Then at increasing of combustion chamber height temperature in the furnace of the boiler also increases and reaches its maximum at 1399 °C on the level of burners. At further increase of combustion chamber height temperature decreases smoothly and at the exit of the furnace has the value 1090 °C.

In the second case at burning of Irsha-Borodinsk coal (curve 2), temperature in the middle of sloping bottom height has the value 975 °C, then the temperature rises sharply to 1000 °C on the level of burners axis (fig. 6). At further examining of temperature change throughout the height of the furnace it is seen that temperature reaches maximal value 1135 °C more burners level at the height 11,8 m. Then temperature decreases step-by-step and at the exit of the furnace it has the value 1040 °C.

Modeling supply of D type Kuznetsk coal into the furnace through the same uniflow burner units that were used at burning Irsha-Borodinsk coal it is stated that temperature distribution in boiler furnace has approximately the same view (fig. 6, curve 3).

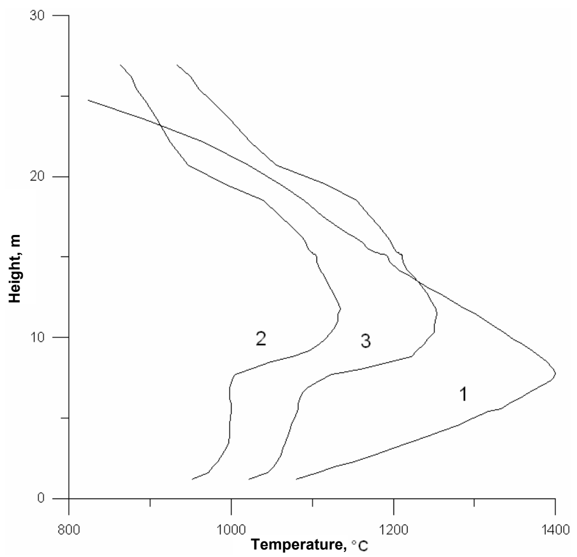


Fig. 6. *Change of average temperature throughout the height of the furnace at burning: 1) Ekibastuz; 2) Irsha-Borodinsk; 3) Kuznetsk coals.*

Temperature on the level of sloping bottom has the value 1060 °C. At a height of combustion chamber, where burner units are installed, temperature has the value approximately 1100 °C and rises uniformly throughout the height of the furnace, reaching its maximal value 1253 °C at height 11,4 m. Then temperature decreases uniformly throughout the height of the furnace and at its exit has the value 1130 °C.

These data indicate that numerical simulation acieved convergence with calculations by standard method of thermal design acceptable for aims of preproject forecasting: temperature difference at the exit of the furnace was not higher than 50 °C.

Conclusions

Using the original applied program package FIRE 3D allows us to obtain the general view of isolines field and parameters of aerodynamics, burning, heat-exchanging, particles interaction with enclosing surfaces of combustion chamber for various ways of organization of solid fuel torch burning. The collection of these results, complemented by their interpretation in three-dimensional visualization, significantly increases opportunities for choosing the variant of power boiler conversion to non design fuel in comparison with traditional approaches to pre-designed examination of the same engineering task.

The scheme of dust burning with one-tier arrangement of uniflow burners in the same breasts instead of swirling ones and at two-eddy integration, which advantage is the least volume of furnace reconstruction at conversion of the boiler BKZ-420-140 to substitutional coal, is unsuitable for burning Kuznetsk mineral carbon of D type, as the conditions for safe performance of boiler heating surfaces and minimization of toxic outbursts are not provided. The given scheme is compatible with properties of brown Irsha-Borodinsk coal and creates favorable conditions in comparison with other examined variants: of temperature level in active combustion zone, that reduces nitric oxides generation; of uniformity of thermal load on evaporation heating surfaces, of temperature of combustion gases at the exit from the furnace that decreases intensity of formation of ash-slad deposits on convective heating surfaces of superheater; of area of forecasted slagging zones of furnace shields that allows reducing quantity of purification apparatus, installed in the furnace.

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