Investigation of inner aerodynamics of the four-vortex furnace model

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Abstract. The internal aerodynamics of a perspective vortex furnace chamber of a pulverized coal boiler with a diagonal arrangement of burners is studied using the non-contact optical method of flow diagnostics. The results of laser Doppler anemometry, characterizing the complex spatial structure of a swirling flow in an isothermal laboratory model of the furnace device, are presented. The velocity distribution in the vortex chamber volume is obtained, and the flow structure in the form of four conjugate closed vortices with curved axes is visualized.

The solution of the topical thermal power engineering problem of expansion of the fuel and raw materials base through the use of low-grade (non-projected) coals involves the development of new types of combustion devices that meet modern requirements for energy efficiency and environmental safety. One of the promising technologies in this area is the combustion of fuel in the vortex flow. Achievement of high indicators for flaring of fuel in the vortex flow is mainly provided by the optimal organization of the flow structure in the combustion chamber. The justification of the choice of constructive and regime parameters requires complex modern scientific methods of physical and mathematical modeling of transport processes in bounded multiphase turbulent swirling reacting flows.

The purpose of this paper is to obtain data on the flow structure in a perspective vortex combustion device for burning pulverized coal with solid ash removal [1]. The investigated design with the original aerodynamic scheme (Fig. 1), applied on a number of boilers of TPP in the Krasnoyarsk region, ensures stable combustion of high-ash coals. At the same time, in practice a number of shortcomings, related to the slagging of heat exchange surfaces, have been revealed. Increasing the effectiveness of this technology requires detailed scientific studies to optimize the design and operation modes of the combustion device [2] based on modern methods.

An experimental study of the inner aerodynamics of this vortex furnace has been carried out on a laboratory isothermal model (Fig. 2) made of 10 mm thick Plexiglas at a scale of 1:25 (internal dimensions of 290x880x730 mm). On the side walls in three tiers there are two diagonally directed nozzles at an angle of 6° (dimensions of 28x50 mm), their axes are directed to the center of the furnace. The front and rear nozzles are also installed in three tiers on the front and back walls (at the same height as the side nozzles) and directed towards the side walls at an angle of 20°. The size of the front nozzle is 23x66 mm, the rear one is 11x64 mm.
The studies were carried out on an experimental stand [3], the main elements of which are (Fig. 2): an automated complex for regulating the supply of compressed air; isothermal laboratory model of a four-vortex furnace; and controlling instruments. The stand is connected to the compressed air supply and ventilation system; and it is equipped with a device for seeding the flow by tracers - microdroplets of glycerin-based liquid (Martin Magnum 1800 fog generator).

To visualize the structure of the flow, a three-component laser Doppler anemometer LAD-056 produced by IT SB RAS was used. The method is based on the measurement of displacements of particles suspended in a flow (tracers). Crossing the interference field, the particles generate an optical signal whose frequency is directly proportional to their velocity.

Measurements of the averaged velocity are carried out in a number of sections of the model at grid nodes with a spatial step of 10 mm. At each node, for at least 20 seconds, at least 1000 measurements are taken for each of the three velocity components (up to 400 samples per second). The regimes with different values of the flow velocity at the nozzle outlet are investigated. The characteristic value of the Reynolds number calculated for the length of the vortex chamber is Re > 105, i.e. the results are obtained in the Re range, which ensures the self-similarity regime of the flow [4], and is applicable to analysis of the flow structure in real-scale furnaces.

Fig. 3 shows the characteristic velocity field in the horizontal section of the model, demonstrating the flow structure with four closed vertical vortices with mutually opposite directions of rotation (the regime at which the velocity at the exit from the side and central nozzles was V0 = 5 m/s is shown). In the vertical section (Fig. 4), one can see that the flow is characterized by ascending jets.

**Figure 1.** The scheme of flow in the furnace:
1 - front nozzles; 2 - side nozzles; 3 - rear nozzles (tertiary air).

**Figure 2.** The photo of the experimental stand: 1 - four-vortex furnace model; 2 - front nozzles; 3 - rear nozzles; 4 - side nozzles; 5 - ventilation; 6 - measuring system LAD-056; 7 - coordinate-moving device.
The value of the $z$ component of the velocity $V_z$ changes its sign twice along the horizontal line $x = 150$ mm (Fig. 5), which corresponds to the location of the conjugate vortices with vertical axes (in the figures there are no velocity measurements in areas not available for optical measurements). The position of the vortex centers ($V_z = 0$) depends on the vertical coordinate $y$, which indicates the curvature of the rotation axes of the vortices. It is known that the screw-like vortex structures observed in the models of power apparatuses turn out to be nonstationary under certain conditions - it is a precession of vortices [5, 6]. In practice, this means the presence of low-frequency pulsations of pressure, which adversely affect the operation of the equipment.

Figure 3. The field of average velocity in the horizontal section at the level of the lower tier of nozzles (top view).

Figure 4. The field of average velocity in a vertical section passing through the centers of the side nozzles (side view).

Figure 5. The distribution of the $z$-component of the velocity: 1 - the lower tier of the nozzles; 2 - the middle tier; 3 - the upper tier.
The results obtained on the basis of high-precision non-contact measurements allowed analyzing the spatial structure of the flow in a vortex furnace, to visualize the characteristic scheme of the averaged flow with four conjugate screw vortices. A modern methodological base for further experimental studies of the flow stability and the effect of regime parameters on the local characteristics of heat and mass transfer has been created with the aim of improving the technical and economic performance of the combustion device. The presented data are applicable for verification of mathematical models used for full-scale numerical calculations of furnace processes [7] for scientific substantiation of effective ways to control the flow structure in order to reduce toxic emissions and prevent slagging of heat exchange surfaces.

The study was carried out with financial support of the Russian Science Foundation (project No. 14-29-00093).

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