Inner aerodynamics of the improved 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: Particle Image Velocimetry - PIV. The results of PIV measurements, characterizing the complex spatial structure of a swirled 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.

1. Introduction
Combustion of fossil fuels (such as coal) currently is the main source of electrical and thermal energy provided. The exhaustion of reserves of high-quality fuel (high calorific value, low ash content and high environmental performance) necessitates the involvement of low-grade coals in the fuel and raw material base. The use of such coals is difficult to implement due to the lack of combustion technologies that provide modern energy and environmental indicators. One of the promising technologies is the combustion of fuel in a vortex flow. Flow swirling allows intensification of the processes of ignition and combustion of the fuel and to achieve uniformity of the temperature field and reduce its average value, which leads to a decrease in the level of toxic combustion products. Optimization of the internal aerodynamics of these devices through laboratory modeling is the first step in their development and modernization.

In this paper in continuation of previous work [1] the flow structure in a model of improved four-vortex combustion device for burning pulverized coal is investigated. The main difference of this furnace from applied on a number of boilers of TPP in the Krasnoyarsk region [2] is the symmetrical arrangement of the front burners (Fig 1-a). This change was introduced to ensure symmetry and stability of the four-vortex combustion scheme.

2. Experimental setup and technique
An experimental study of the inner aerodynamics of this four-vortex furnace has been carried out on a laboratory isothermal model (Fig. 1-b) 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 (main burner slots) at an angle of 6° (dimensions of 28x50 mm), their axes are directed to the center of the furnace. The front nozzles (secondary air) 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 nozzles is 23x66 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 oil.

In this the PIV-system “Polis” for measuring two components of velocity simultaneously for the entire cross-section was used. The measuring of instant velocity field in a given cross-section is based on recording of tracer particles replacement between two laser flashes. The replacement value is found using correlation methods applied to tracer patterns when the plane is divided into regular elementary zones. The PIV measurement complex includes: a double pulse Nd:YAG-laser QuantelEVG with the pulse energy of 145 mJ and pulse duration of 10 ns; a lens for generating a laser sheet; CCD camera ImperX B4820 with resolution of 4904×3280 pixels; lens Nikon with focal length of 50 mm; a synchronizing processor; a computer with software ActualFlow and code package PIV Kit; and the
assembly kit based on the Newport elements. The coordinate tool was used to shift the measurement system; the positioning accuracy within the furnace model was defined by the coordinate step at least 0.1 mm.

PIV measurements were performed for a set of horizontal cross-sections. For every cross-section, the system records a series of 1000 couples of frames taken with the frequency of 1.25 Hz (time delay within the frame couple equal to 100 µs). The data processing was performed using the iteration cross-correlation algorithm for computing the velocity filed: the computation domain was divided into cells with the size of 64×64 pixels and spatial over-lapping by 50 %. The background glow produced by light reflection from model’s components was eliminated with the digital filtration of the image (“background filtering”).

3. Results

Fig. 3 presents the time-average velocity fields within the model of four-vortex furnace (for several horizontal cross-sections matched to the centers of each burner tiers). The flow regime at the exit velocity of 5 and 2 m/s for the side and front nozzles, respectively, is presented. Preliminary studies have shown that with such a ratio of velocities the pronounced four-vortex structure of the flow is observed. The ratio of velocities corresponds to the values used on real boilers. 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. For better visibility the entire velocity field has been produced by mirroring of the measurement results relative to the symmetry plane, passing through the centers of the front nozzles. Therefore the better spatial resolution and lower computing time were achieved by taking the flow image only for a half of horizontal cross-section only (290×365 mm). The minimal spatial step in the grid for this domain was 5 mm.

![Figure 3](image_url)

**Figure 3.** Vector fields of time-averaged velocity for the flow regime when the initial velocity from side and front nozzles was 5 and 2 m/s, respectively. Three horizontal cross-sections: (a) bottom nozzles; (b) middle nozzles; (c) top nozzles.
As one can see, the flow has a complex spatial structure. Streams flowing from the side nozzles at a distance of 5 calibers combine and spread to the center of the furnace. Colliding they turn back and mix with the streams, outcomes from the front nozzles, and then flow along the front walls to the side wall, therein forming four vertical vortices. Such a structure is observed along all three tiers. Streamlines, shown in Fig.4-b, also indicate the presence of four conjugate vortices. Thus, with the regime parameters under study, a stable four-vortex flow scheme is formed. However, the limits of its existence are to be clarified as a result of additional research.

**Figure 4.** Structure of the flow in the four-vortex furnace (streamlines).

**Conclusion**

Using the PIV method the information on velocity distribution in an isothermal laboratory model of the improved four-vortex furnace device has been obtained. The flow structure in the form of four conjugate closed vortices with vertical axes has been visualized. The results obtained are the first stage in the study of the complex spatial structure of a swirled flow in a four-vortex furnace model, and will be used in further experimental and numerical investigation.

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