3D-LDA diagnostics of a swirled flow in the model of an improved four-vortex furnace

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Abstract. The three-component Laser Doppler Anemometry method (3D-LDA) was used to study the internal aerodynamics of an experimental model of a promising furnace with a four-vortex scheme for burning coal fuel. Distributions of the averaged velocity and velocity fluctuations are obtained. There are no pronounced peaks in the spectrum of velocity fluctuations, so we can speak about the stability of the investigated flow. The studied model is characterized by a high level of velocity fluctuations, provided for effective mixing of the pulverized coal mixture in the combustion chamber of the furnace.

Introduction
Coal combustion continues to dominate the power generation market [1-3]. At that, thermal power plants using coal as a source of energy still face strict requirements concerning the level of harmful emissions (NOx, CO, CO2, SOx and soot) in comparison with other fuels [4]. The study of fundamental laws and processes in the development of new types of furnaces is one of the most important tasks in the creation of energy-efficient and environmentally friendly boiler equipment that meets international standards.

There are a lot of furnaces that use the vortex combustion schemes [5-9]. In such furnaces it is possible to burn low-quality coal fuel with a low level of pollutants by organizing the aerodynamics of the device (without any additional cleaning devices). Unfortunately, the combustion of coal in such furnaces is often accompanied by the emergence of unstable vortex structures of various types (precessing vortex core or others), which prevent their use. Thus, laboratory modeling of aerodynamics of the developed furnaces in order to identify such structures can help in the development of design and operating parameters for effective implementation.

This work is devoted to the study of spatial structure of a turbulent flow in a laboratory four-vortex furnace model proposed in [9]. Previously, the method of Particle Image Velocimetry (PIV) was used to determine the zone of vortex localization and the optimal regimes for providing a symmetrical four-vortex flow pattern.

Experimental setup and procedure
Experiments have been carried out with the help of the test model of an improved four-vortex furnace (290×1200×730 mm) made of transparent plexiglass. The scheme of this model is presented in Fig. 1.
The model consists of combustion chamber (1); frontal (2) and side (3) nozzles, mounted in 3 tiers; and ventilation (4). The side nozzles are diagonally directed to the model center. Front nozzles are directed to the side walls using separators (~20°). Due to this arrangement of the nozzles, four symmetrical vortices are formed inside the model. Air supply from the main line is carried out using an automated system. The experimental setup is described in more detail in [9].

To evaluate the velocity components in the measuring area, the 3D-LDA technique was applied. For this, a three-component anemometer LAD-056, consisting of two two-dimensional devices, was used. The gauge (5) was mounted on the moving coordinate device (6) in front of one of the walls (see Fig. 1). The experiments have been performed with a spatial step of 5 mm in the area of vortex localization, determined in the PIV studies [9]. The zone (7) between the centers of the bottom and top tiers of the burners was oriented vertically and it was limited to one passage of the coordinate device (240 mm). Measurements at every point were taken over the time required to obtain at least 5000 measurements for each component. These measurements were sufficient to ensure that the error in determining the mean value was not higher than 10% in the 95% confidence interval [10].

![Figure 1](image.jpg)

**Figure 1.** Scheme of the laboratory model: 1 – Combustion chamber; 2 – Side nozzles; 3 – Central nozzles; 4 – Outlet; 5 – 3D-LDA velocimeter; 6 – Coordinate-moving device; 7 – Measuring area.

**Results**

To investigate the spatial structure of the swirled flow in the test model of four-vortex furnace, several series of experiments were carried out: three velocity components in the area of vortex localization were measured (40×240×75 mm; red area in Fig.1). Due to some peculiarities of the model and measuring equipment, the entire volume of the furnace was unsearchable for measurements, so they were carried out only in one quarter. Since we investigate the regime implementing a symmetric four-vortex scheme [9], the measurements performed are sufficient to analyze the flow structure in the entire volume of the model. The velocity vector field, constructed by the results of 3D-LDA measurements in the horizontal cross-section near the center of the middle tier, is presented in Fig. 2. The regime with the average velocities of 4 and 2 m/s, respectively, at the outlet of the side and central...
nozzles (the total air flow rate is 350 m$^3$/h) is presented there. The presented velocity field shows that in horizontal sections the flow is swirled with a velocity value of less than 1 m/s.

![Figure 2](image)

**Figure 2.** The vector velocity field in horizontal cross-section near the center of middle tier.

As it is noted above, the stationarity of the swirling flow is of particular interest for practical application. To study the flow stability, we examine velocity fluctuations with the help of the fast Fourier transform by analogy with [11]. The resulting spectrum of fluctuations of the $z$-velocity component at point $(x; y; z) = (55$ mm; 120 mm; 125 mm) is presented in Fig. 3-a. There are no pronounced peaks which characterizes the stability of the studied flow (absence of precessing vortex core or any other phenomena). In addition, the profile of RMS $z$-velocity component, normalized to the average flow velocity, is shown in Fig. 3-b. Let us note that the flow is characterized by a high level of velocity fluctuations (up to 30% of the average flow rate). At that, distribution of fluctuations over the vortex cross-section is rather uniform, which in practice will ensure effective mixing of the supplied pulverized coal mixture with the reacting flow, and this is an advantage for coal combustion devices.

![Figure 3](image)

**Figure 3.** The $z$-velocity fluctuations spectrum at the point $(x; y; z) = (55$ mm; 120 mm; 125 mm); (b) profile of RMS deviation of the $z$-velocity normalized to the average flow rate velocity (3 m/s).
Conclusion
We have measured the spatial distribution of velocity in the test model of a modernized four-vortex furnace using the 3D-LDA. The results of experimental studies visualize the spatial structure of the swirled flow. When analyzing velocity fluctuations with the help of the fast Fourier transform, we failed to reveal any pronounced peaks demonstrating the presence of unsteady vortex structures. The absence of such structures indicates that there is a stable swirling flow inside the combustion chamber. At that, the flow is characterized by a relatively high level of velocity fluctuations in a wide range of frequencies, which is an advantage of the studied furnace, since it can ensure the effective mixing of flows when applying this scheme for pulverized coal combustion.

The next stage of research will be verification of the mathematical model for modeling the processes of fuel combustion in a real-scale furnace.

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