

Isothermal modeling of aerodynamic structure of the swirling flow in a two-stage burner

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Abstract. The work deals with the experimental study of the aerodynamic structure of a swirling flow in the isothermal model of two-stage vortex combustion chamber. The main attention is focused on the process of flow mixing of two successively connected tangential swirlers of the first and second stages of the working section. Data on flow visualization are presented for two patterns of flow swirling. Time-averaged profiles of the axial and tangential velocity components are obtained with the help of laser-Doppler anemometer. In the case of flow co-swirling between two stages of the working section, instability of a secondary flow in the form of precessing vortex was distinguished. For the regime with counter flow swirling, effective mixing of the swirl flows was found; this was reflected by formation of the flow with uniform distribution of axial velocity over the cross-section.

1 Introduction

Investigation of the vortex flows is a significant part of the modern fluid dynamics. Flow swirling can make a considerable contribution to the transport processes. Therefore, the swirling flows are widely used in many industrial processes to sustain atomization of liquid fuel, liquid mixing, formation of aerosols and stabilization of flames. Intensive heat and mass transfer occurring in the swirling flows and increased level of flow turbulence are used for cooling/heating and cleaning the working liquids, suspension separating, separation of materials and many other technological purposes. The devices, based on working medium swirling, are used in hydropower engineering, thermal power engineering, petroleum and chemical industries and many other fields [1].

Currently, one of the most interesting problems in the field of swirling flows is investigation of characteristics of behavior of the interacting swirling flows [2-3]. The need for such research is firstly caused by the use of the counter-swirling flows in energy dissipation devices and vortex combustion chambers. To optimize the process of flow mixing in these devices, it is necessary to understand the flow structure and mixing mechanisms. These studies are specifically relevant for modernization and improvement of the vortex combustion chamber [4]. In particular, this relates to the problems of the most efficient combustion of fuel, reducing pollutant emissions and increasing the operational lifetime of power plants [5-8].

2 Experimental methods

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Isothermal modeling of a two-stage burner was carried out using water as a working liquid. To study experimentally the aerodynamic structure of a swirling flow, the transparent model of a vortex chamber with two-stage flow swirling was made. This chamber (6) was connected to the hydrodynamic circuit (Fig.1), consisting of vessel (1) with tankage of 0.5 m³, centrifugal pump X100-80-160T153 (2) with maximal flow rate and head of 100 m³/h and 4 atm., respectively, lines of liquid supply to the first and second stages with the flow meters in every line (4 – metering orifice, 5 - vortex-acoustic flow meter Metran-300PR). The total flow rate was regulated by the frequency converter Vesper E2-8300-030N (3), and flows through each line were controlled by the regulating valves. Together with the flow rates between the stages, it was possible to measure flow swirling on the second stage of the model.

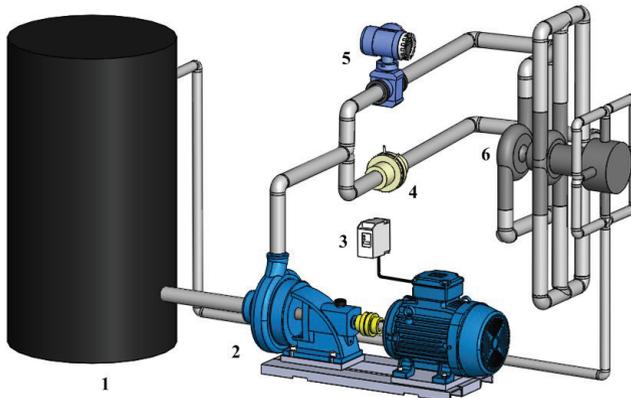


Fig.1. Scheme of hydrodynamic setup for modeling the aerodynamic structure of the swirling flow in the two-stage burner. 1 – vessel, 2 – pump with electromotor of 22-kW power, 3 – frequency converter, 4 – metering orifice, 5 – vortex flow meter, 6 – working section.

The hydrodynamic model of the two-stage burner is used as the working section (Fig. 2). This chamber consists of two successive swirlers with the diameter of 185 mm, where the flow is swirled by means of tangential supply through the pipe sockets with the inner diameter of 40 mm. The liquid flow is swirled by swirler (1), then, passing through a nozzle, it is fed to the zone of sudden expansion. Then, in this zone, it interacts with the flow, swirled by second swirler (3). Depending on the method of liquid supply to the second swirler, co-swirling (white arrows) and counter-swirling (dark arrows) of two flows are achieved between the swirlers of the first and second stages of the working section. The resultant flow from the cylindrical zone of 104-mm diameter (4) is fed to the outlet section (5), and it leaves it through four symmetrical pipes with the inner diameter of 20 mm.

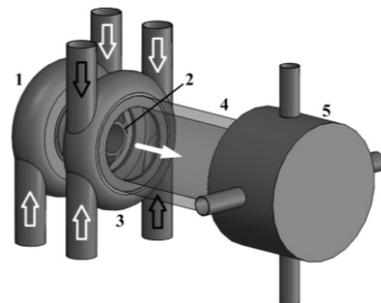


Fig.2. Scheme of hydrodynamic model of two-stage burner. 1 and 3 – swirlers of the first and second stages of the burner, respectively, 2 – shaped nozzle, 4 – zone of sudden expansion, 5 – outlet section with outlets and deswirler blades.

3 Experimental results

3.1 Visualization

The flow was visualized during the experiments on the isothermal model. Small air bubbles were used as the flow markers. These bubbles were illuminated by a light source (diode

floodlight), to obtain the general flow pattern, or by a narrow light “sheet” formed via sweeping a laser beam on a cylindrical lens, to visualize the flow structure in a certain cross-section of the working section.

The flows with co-swirling and counter-swirling were visualized for different ratios of liquid flow rates between the stages of the working section. According to analysis of visualizations, the regime characterized by the aerodynamic flow structure, optimal from the point of efficient flow mixing at the first and second stages, was determined. Results of visualization of the flows with co- and counter swirling in both longitudinal and transverse cross-sections of the vortex chamber are presented in Fig. 3. The experiments were carried out for the liquid flow rates of 4 m³/h at the first and 6 m³/h at the second stages of flow swirling. For the cases of flow co-swirling, the high-speed recording (Fig.3 (c, d)) demonstrates the presence of secondary flow instability with formation of a precessing vortex at the boundary of the central stagnation zone, that causes induction of powerful low-frequency flow pulsations of a discrete frequency. In contrast to the flow with co-swirling, the version with counter-swirling showed efficient interaction of the swirling flows of the first and second stages. The resultant flow was characterized by uniform distribution of the axial velocity along the cross-section in combination with relatively expressed total rotation of the flow in the working section. The absence of large-scale non-stationary structures and, consequently, intense flow pulsations is the feature of this flow regime.

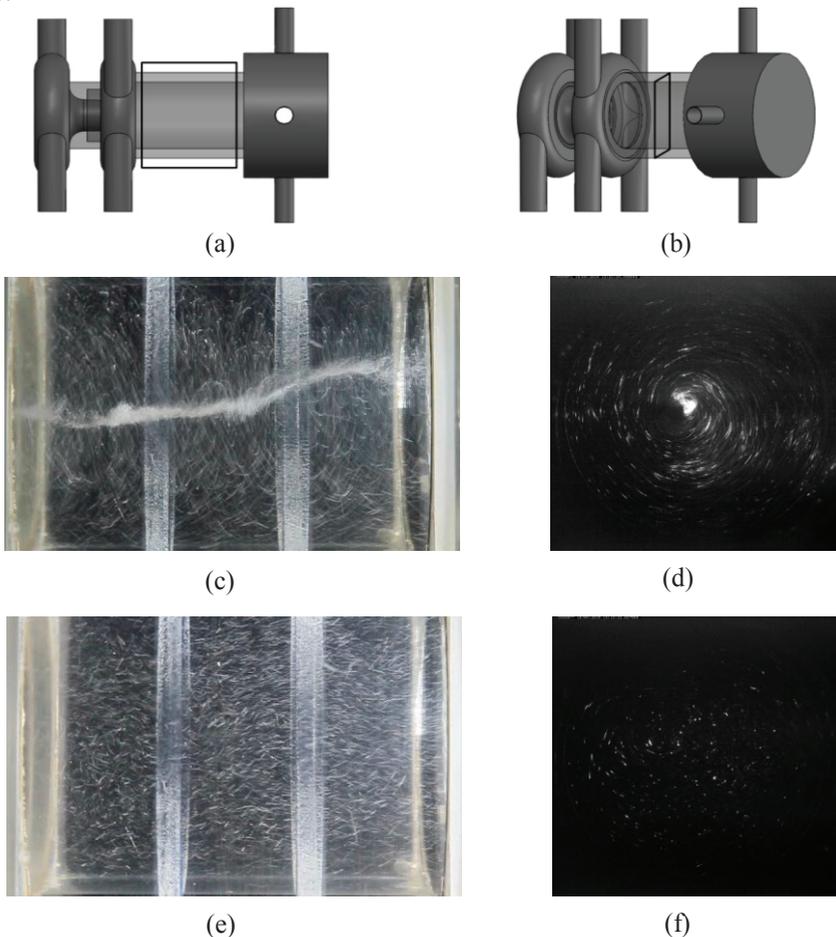


Fig.3. Flow visualization under different conditions of vortex chamber operation. Position of visualization area: a – side view, b – transversal cross-section. Regime with flow co-swirling: c – side view, d – transversal cross-section. Regime with flow counter-swirling: e – side view, f – transversal cross-section.

3.2 LDA measurements

To get quantitative information about the flow field, the two-component laser Doppler anemometer (LDA) LAD-06i was used. Time-averaged axial and tangential velocity components were measured along three lines in the cross-section of the cylindrical zone of sudden expansion (Fig. 4). The characteristic distances from the second stage of flow swirling to the measured areas are shown in Fig. 4. The spherical polystyrene particles with neutral buoyancy were used as the flow tracers in LDA measurements. The presented results were obtained for the liquid flow rate of 4 m³/h at the first and 6 m³/h at the second stages of flow swirling. The distance from the central axis r is normalized to radius R_0 of the cylindrical area of sudden expansion (Fig. 2 (4)).

In the case with flow co-swirling (Fig. 5), we can see formation of the axial flow, non-uniform over the cross-section, with intense flow along the sidewalls and extended area of a stagnant flow along the chamber axis. In the case of flow counter-swirling (Fig. 6), the resultant flow structure is characterized by uniform distribution of axial velocity over the cross-section in combination with relatively expressed rotation of the flow in the working section.

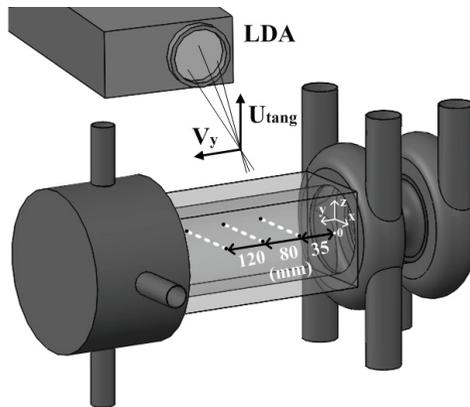


Fig.4. Layout of measurement sections

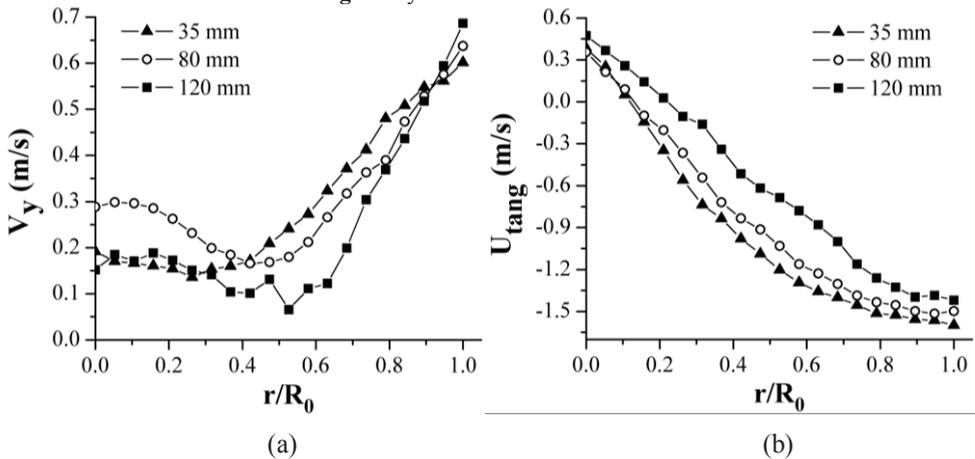


Fig.5. Velocity profiles for different conditions of vortex chamber operation. a, b – axial and tangential velocity components, for the regime of flow co-swirling.

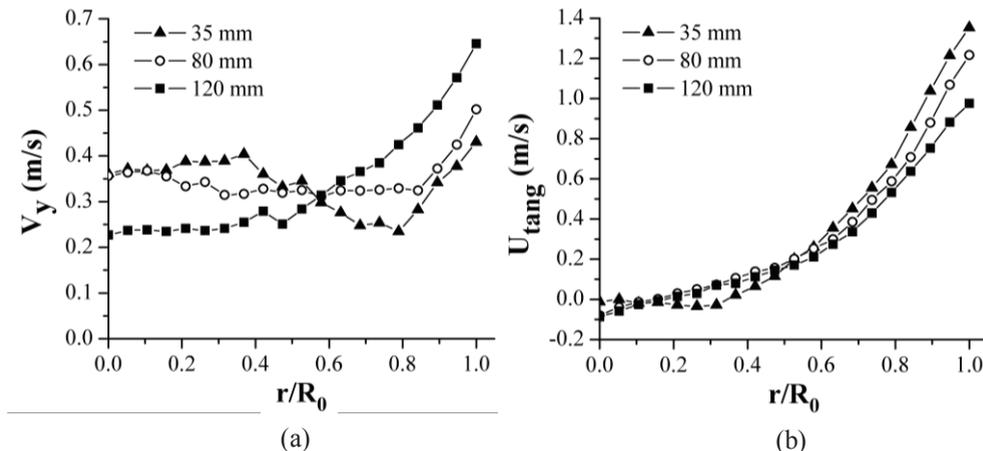


Fig.6. Velocity profiles for different conditions of vortex chamber operation. a, b – axial and tangential velocity components, for the regime with flow counter-swirling.

4 Conclusion

During this study, the high-speed recording of the flow was carried out for two types of flow swirling. When the flows were swirled in one direction, formation of a precessing vortex, generating low-frequency pressure pulsations in the flow, was revealed. The flow with swirling in different directions showed uniform filling of the working section in combination with moderate flow swirling and flow stability. Time-averaged profiles of axial and tangential velocity components, obtained using the two-component LDA, demonstrated that in the case of co-swirled flows the non-uniform distribution of axial velocity is observed in the cross-section with a strong flow along the sidewalls. In turn, the characteristic profiles of axial velocity component in the case of counter-swirled flows showed uniform distribution, which characterizes the effective mixing of two flows.

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