Features of swirled flows in power plant chimneys

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Abstract. The results of computational studies of the cylindrical and conical chimneys operating modes are presented. It is shown that with opposite gas supplies, swirling flows appear. Their shape and intensity depend on the type of chimney stack and the gas supply conditions. Swirling flows significantly affect the fields of axial and tangential velocities and determine the conditions for the gas outflow from the chimney.

1. Introduction

Important questions of the reliable chimneys’ operation and the flue gases dispersion in the adjacent territory are the design of their chimney stacks and the choice of the optimal connection scheme with operating boilers. In addition, the peculiarities of the gas flow in the chimney stack affect the choice of the measuring systems installation place for the TPPs pollutants monitoring and emission accounting system.

The numerical investigations have been carried out to solve these questions. The exhaust gases swirling flows in cylindrical and conical TPPs chimneys have been studied.

2. The object description and the research method

Gas flow numerical experiments were carried out for two types of reinforced concrete chimneys – cylindrical and conical ones.

A cylindrical chimney with 125 m height and 4.2 m diameter has a metal stack. It extracts flue gases with a total flow rate of 430 nm³/h (nominal rate). In its lower part, in the gas injection unit, a dividing wall is installed at the angle of 40° to the direction of counter gas flows and ramps located parallel to the dividing wall at an angle of 36.8° to the horizon (Figure 1a). The 5.2 m high diffuser with an outlet diameter of 5.2 m is installed in the upper part of the cylindrical pipe, in order to prevent the appearance of excessive pressure and to reduce losses for the outlet of gases at their maximum flow rates.

The conical chimney with 126 m height and 4.9 m outlet diameter has a variable slope from 4.5% at the foundation level to 1.25% at the chimney outlet. There are two diametrically opposite openings for the supply gas ducts input with a cross section of 4.0x10.0 m. These openings are made for supplying chimney by flue gases at an altitude mark of +5 m. A reinforced concrete ceiling with ramps is made under the openings (Figure 1b).

For numerical experiments using CFD methods, the ANSYS software package was used. It allows mathematical modeling of working processes occurring in gas-dynamic systems [1].

The three-dimensional geometry modeling of the computational domains, the computational mesh construction, the models and media characteristics setting, the initial and boundary conditions determination were performed. The computational domains for the simulation implementation were...
represented by the flow parts of the supply gas ducts and chimneys. The preparation of chimneys and gas ducts geometric models, with the real structures’ peculiarities, was carried out in the SolidWorks software (Figure 2). To simulate the gases outflow into the environment a spherical region was used in the computational model. It emulates the behavior of atmospheric air (Figure 2).

Continuous medium (flue gases) motion problem was solved by the RANS method with the SST turbulence model [2]. The Meshing software package built into the ANSYS computational environment was used to construct the computational mesh [1].

Figure 1. The gas supplying area of cylindrical (a) and conical (b) chimneys.

Figure 2. General view of a three-dimensional geometric model.
3. The main research results discussion

The flue gases entrance into the cylindrical chimney is almost symmetrical because of the ramp and the dividing wall (Figure 1a). There are no such devices at the conical chimney inlet (Figure 1b). It leads to a front collision of the incoming gas flows, their unsteadiness and irregularity (Figure 3) as well as local resistance increase.

![Figure 3. Flue gases streamlines in cylindrical (a) and conical (b) chimneys.](image)

Gas flows swirl and then make a lifting motion along a complex spiral trajectory despite the noted difference in the lower inlet sections design. It is evidenced by their streamlines in the chimney stack (Figure 3) and absolute velocities longitudinal components vectors in the cross-sections along the chimney height (Figure 4). The shape of chimney stack affects less on the swirling flows structure comparing the dividing wall installation at the chimney inlet and the diffuser at the chimney outlet in this case.

Calculations have shown that in a cylindrical chimney with a dividing wall in its lower part, two practically symmetric elliptical vortices are formed, which rotate in opposite directions (Figure 4a). This is a result of the incoming gas flows interaction along the entire height of the chimney stack. Moreover, their vertical axes are quite stationary and practically do not change their position. This confirms the research results of [3] on the flue gas flow swirl existence in the case of symmetrical chimney stack supply.

As a result of the initial flow swirling at the entrance of cylindrical chimney, the flow core is displaced relative to the longitudinal axis of the chimney (Figure 5a). It leads to the irregularity of the ascending flow in the cross-sections of the chimney (Figure 4a). Further, when gases enter the diffuser in the upper part of the stack, deformation and partial destruction of vortices occurs with spreading of the gas flow along the chimney walls. It leads to the appearance of an irregular and asymmetric upward
flow along these walls. As a result, an asymmetric gas jet is formed at the chimney outlet. This occurs even in case of the wind load absence (Figure 5a).

![Velocity Axial](image)

\[ \text{Velocity Axial} \quad [\text{m s}^{-1}] \]

+17 m  +43 m  +17 m  +43 m  
+69 m  +95 m  +69 m  +95 m  
+120 m +126 m  +120 m +126 m

(a)  (b)

**Figure 4.** Axial velocity and velocity vectors in cross-sections along the cylindrical (a) and conical (b) chimneys height.

The flue gas flow inside the cylindrical stack has a fairly stationary character at all loads. With the gas flow rate decrease, the upward flow swirling intensity decreases in comparison with the maximum load regimes. This reduces slightly the flow irregularity in the chimney stack cross-sections along its height but increases the stagnant zone size in the diffuser outlet. At the same time, due to the specificity of swirling ascending flows, the axial velocity maximum reaches 60 m/s, and its minimum reaches about 30 m/s.

There is an intense interaction of opposite incoming gas flows (Figure 5b) in the conical chimney due to the absence of a dividing wall. This leads to four chaotic asymmetric vortices formation in the lower part of the chimney stack (Figure 4b). Then they merge into a single spatial vortex of the "tornado" type (vortex tube) along entire chimney height (Figure 3b). The stream vertical axis makes a rotational motion ("whirligig effect") in this case. So, the vortex tube precession takes place. As a result, the gas flow tangential velocity in the chimney stack cross-sections has a certain unevenness (Figure 4b).

The gas flow axial velocity distribution peculiarities in the conical chimney are explained both by the inlet conditions and by the stack shape. There are large velocity irregularities and small areas with a negative vertical velocity component at the chimney inlet (Figure 3b) due to the absence of a dividing
wall. However, the flow quickly smooths and the velocity field in the chimney cross-sections becomes almost uniform at the initial section already.

![Flue gas flow axial velocity in cylindrical (a) and conical (b) chimneys.](image)

**Figure 5.** Flue gas flow axial velocity in cylindrical (a) and conical (b) chimneys.

The flue gases ascending flow inside the stack occurs with acceleration due to the narrowing of its conical shape. In this case, the axial velocity along the height of the chimney stack increases from 20 m/s at the inlet to 40 m/s at the outlet. As a result, the dynamic pressure increases, and the static pressure decreases. Nevertheless, the field of velocities in the cross-sections of the pipe is practically uniform (Figure 4b). This happens primarily because the stack is essentially a confusor. As a result, the flue gas flow velocity equalizes, and its total pressure increases.

The vortices intensities in cylindrical and conical chimney stacks differ significantly, but there is a tendency of their decrease along stack height in general. The vortices intensity can be quantitatively expressed through the ratio of the swirling upward flow tangential and axial velocity maximum values in various cross-sections of the chimney stack along its height. So, for a cylindrical stack with a dividing wall, the intensity of both vortices at maximum loads decreases from about 30% in the lower part to 5%
in the outlet diffuser. For a conical chimney without a dividing wall with a single spatial vortex at the inlet, a similar decrease was from 70% to 20%. Approximately the same quantitative characteristics of the vortices intensity for both chimneys were retained even at the minimum (50%) gas flow rates.

4. Conclusion
The computational studies results are used to optimize the exhausting flue gases regimes and to organize the pollutants emissions instrumental control into the atmosphere on TPPs’ chimneys.

References
[1] Roslyakov P V, Khudyakov I V, Khokhlov D A and Zaichenko M N 2019 Experience Gained with CFD-Modeling of Liquid and Gaseous Fuel Combustion Processes in Power Installations (Review) Thermal Engineering 66(9) 599–618
[2] Menter F R 1993 Zonal Two Equation k-ω Turbulence Models for Aerodynamic Flows. 24th Fluid Dynamics Conference: (AIAA) Paper 93-2906
[3] Roslyakov P V, Kondrat’eva O E and Kubysheva L L 2015 Organizing Continuous Monitoring and Recording of Atmospheric Pollution at Thermal Power Plants. Power Technology and Engineering, 49(4), 296–300