Investigation of pulverized coal flaring based on eddy-resolving turbulence models

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Abstract. Calculation studies of the effect of the turbulent flow simulation method on the combustion processes of swirling pulverized coal flow have been performed. A comparative analysis of the results of mathematical modeling with experimental data has shown that the DES and LES methods can correctly resolve the complex vortex structure of a coal torch. It was found that the choice of turbulence simulation method when calculating the combustion of swirling pulverized coal flow has a significant impact on the results of the numerical experiment.

1. Introduction
Numerical simulation of furnace units is one of the most important ways to obtain the most complete information about the processes occurring during the combustion and gasification of pulverized coal fuel. Currently, simulation allows for obtaining reliable information about the operation of industrial combustion equipment [1, 2]. However, for furnace units, where essentially non-stationary combustion modes occur, the application of methods based on the use of stationary RANS turbulence models leads to incorrect results. In this regard, the problem of finding not only fields of average values but also the resolution of large-scale vortex flow structures that determine the processes of pulverized coal fuel heat transfer and combustion becomes urgent.

2. Problem statement and research methods
The URANS k-w SST Mentor model, the LES (Large-eddy simulation) model, and the DES (Detached eddy simulation) model based on the k-w SST model were used for numerical simulation of non-stationary turbulent flow of the furnace medium [3]. The motion of coal particles is described by the equations of the material point dynamics, taking into account the resistance force and gravity. The turbulence of the flow during particle motion is taken into account by introducing random fluctuations of the gas velocity into the motion equation of particles. Coal particle combustion is considered in the form of successive stages: evaporation of moisture from the fuel, the yield and combustion of volatile components, and the combustion of coke residue. The solution of the radiant energy transfer equation is based on the P1 approximation of the spherical harmonics method for a gray two-phase two-temperature medium. The mathematical model is implemented using the Ansys Fluent CFD package.

Experimental data on the combustion of a swirling pulverized coal flow obtained on a 2.4 MW firing test facility were used for computational studies and verification of the mathematical model [4]. The diagram of the firing test facility is shown in Fig. 1. Metering characteristics during experimental studies and those used in the calculation were as follows: primary air consumption of 0.117 kg/s, temperature of 343.15 K, average axial velocity of 23.02 m/s, and coal flow rate of 0.073 kg/s. Secondary air flow
rate equaled to 0.745 kg/s, temperature was 573.15 K, average axial velocity was 43.83 m/s, average tangential velocity was 49.42 m/s. The technical composition of coal (dry wt%) was as follows: volatiles of 37.4, fixed carbon of 54.3, Ac of 8.3. Chemical composition of coal (operating wt%): Sg of 80.36, Hg of 5.08, Ng of 1.45, Sg of 0.94, Og of 12.17, \( Q_a = 32.32 \text{ MJ/kg} \).

A structured grid containing 4 million control volumes was used (Fig. 2). The grid in the torch area was more detailed. The calculated time step was \( \Delta t = 0.00015 \text{ s} \) which corresponded to the Courant number less than unity within the entire calculation area.

![Figure 1](image1.png)

**Figure 1.** Sketch of the firing test facility with a 2.4 MW burner [4].

![Figure 2](image2.png)

**Figure 2.** A calculation grid of the combustion chamber with a vortex burner device.
3. **Results and discussion**

Figure 3 shows the characteristic instantaneous and averaged flow patterns and temperature field in the furnace device.

![Calculation results in the central section (top – instantaneous field, bottom – averaged field): a) Velocity magnitude, m/s, b) Temperature, K.](image)

The results of the stationary calculation for this burner were presented earlier in [5]. The temperature and velocity distribution graphs (Figs. 4 and 5) show that the results obtained using RANS turbulence models deviate significantly from the experimental data. A significant discrepancy in velocity is observed in sections Z=0.25 and Z=0.85 m (from the inlet to the furnace chamber). According to the calculation results (RANS and URANS), in cross-section Z=0.25 m, there is a temperature dip in the area of the torch boundary as compared to the experiment.

The calculation results show that the DES and LES methods allow reproducing correctly the average temperature and velocity field when calculating a furnace device with a vortex burner. The calculated temperature distribution coincides with the experimental data, and the temperature dip in the torch boundary region is significantly smaller than that obtained by using the RANS models.
Figure 4. Distribution of the axial velocity in the cross-sections at different distances from the burner:
a) \( z=0 \) m, b) \( z=0.25 \) m, c) \( z=0.85 \) m.

Figure 5. Temperature distribution in cross-sections at different distances from the burner:
a) \( z=0 \) m, b) \( z=0.25 \) m, c) \( z=0.85 \) m.

Conclusion
The non-stationary numerical simulation method of combustion of swirling pulverized coal flow was developed and verified. The performed computational studies of the swirled pulverized coal flow have shown that the use of the LES (Large-eddy simulation) method and the hybrid DES (Detached eddy simulation) method based on the \( k-\omega \)SST model significantly better describe the averaged characteristics of the flow as compared with the non-stationary approach based on the Reynolds equations, as well as stationary approaches. It is found that the choice of turbulence modeling method when calculating the combustion of swirling pulverized coal flow has a significant impact on the results of the numerical experiment.

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