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Numerical Simulation of Physical and Chemical Processes in Fluidized Bed

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Abstract. The paper presents a numerical simulation of the furnace with a circulating fluidized bed. Numerical study carried out for the bottom of the combustion chamber with the varying heights of volume filling. The results contours of particulate matter concentration and of velocities, as well as a graphical representation of changes in the concentration of particles on the bed height are shown. Simulation performed in Eulerian - Eulerian representation on a 2D model.

1. Introduction

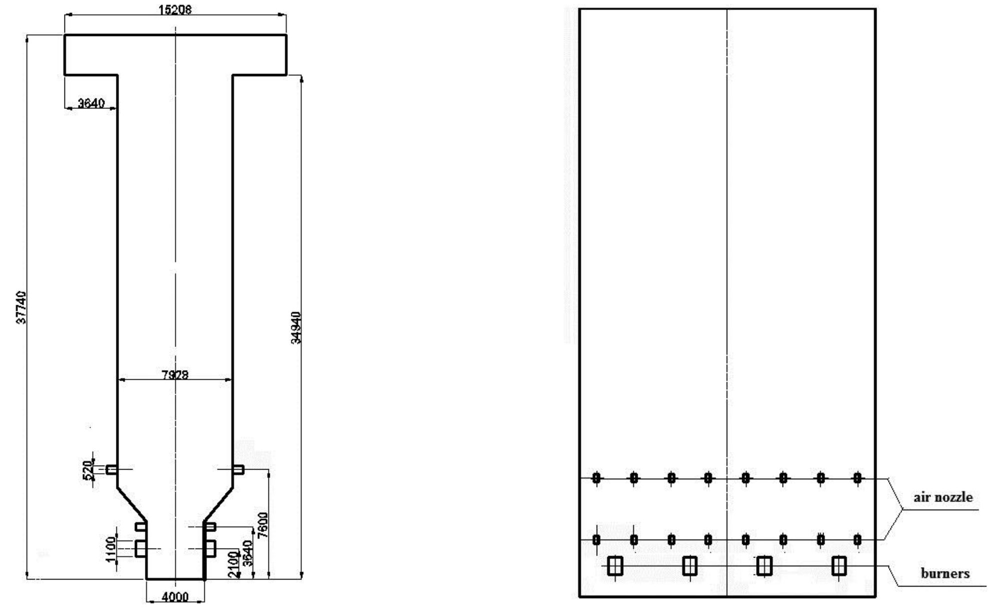
Currently, much attention is paid to technology for to achieving low harmful emissions during effective combustion of low-quality solid fuels. Boilers with circulating fluidized bed (CFB), widespread in the energy sector where fuel is supplied from both the burners and of returning ash chute, became in the bottom of the furnace there is a fluidized bed where a constant particle removal is organized [1].

High-quality design of large stakes of a circulating fluidized bed depends on the analysis of dynamic processes in the furnace. Experimental studies of combustion processes are limited to local areas. Time-consuming for testing and incomplete information about the conditions of functioning the real object as opposed to the numerical simulation of the interest in which is constantly increasing.

Formation of the structure, particle distribution, the speed of solids and other physical and chemical processes are of scientific interest because insufficiently studied objects in the major energy [2, 3]. At present, special attention is paid to two and three-dimensional modeling using Euler-Lagrangian and Eulerian-Eulerian approach.

The object of investigation is selected CFB boiler height of 37.74m and a depth of 4m at the bottom of the furnace and 8m in the main. The boiler is equipped with 8 burners and 2 rows of air nozzles 4 in a row.

Side wall bottom portions form ramps for the purpose of narrowing the furnace and increasing the thermal stress in the fluidized bed. The walls of the furnace in the zone of high thermal stresses are lined with an abrasive material. The upper part of the furnace is divided into 8 flues equipped with inertial separators. Some of the fuel and the ash is returned to the lower part of the furnace after eight burners arranged oppositely four on each side wall. The combustion chamber is equipped with 48 air jets arranged oppositely on the side walls of the furnace in three tiers (figure 1).



(a) (b)

Figure 1. Sketch of the combustion chamber: (a) – a cross-section; (b) – side view.

2. Mathematical model

Mathematical modeling of combustion devices is one of the most important ways of obtaining information about the aerodynamics, the local and the total heat transfer. Obtained information it is necessary for the design and evaluation of new thermal energy units [4, 5].

Simulation of the gas phase was carried out by Eulerian-Eulerian. The continuity equation for gas phase is

$$\frac{\partial(\varepsilon_g \rho_g)}{\partial t} + \frac{\partial}{\partial x_j}\left(\varepsilon_g \rho_g u_{gj}\right) = 0 \tag{1}$$

Here is ε_g – bed voidage; ρ_g – density of gas phase (kg/m^3); t – tracer sampling time (s); u_{gj} – gas velocity (m/s); x_j – direction coordinate.

The continuity equation for particulate phase, is written as

$$\frac{\partial(\varepsilon_s \rho_p)}{\partial t} + \frac{\partial}{\partial x_j}\left(\varepsilon_s \rho_p u_{pj}\right) = 0 \tag{2}$$

Here is ε_s – solid fraction; ρ_p – particle density (kg/m^3; u_{pj} – particle velocity (m/s).

The conservation of momentum for the gas phase is described by

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g u_{gi}\right) + \frac{\partial}{\partial x_j}\left(\varepsilon_s \rho_g u_{gj} u_{gi}\right) = -\varepsilon \frac{\partial p}{\partial x_i} + \frac{\partial \tau_{g,ij}}{\partial x_j} - \beta\left(u_{gi} - u_{pi}\right) + \rho_g \varepsilon_g g_i \tag{3}$$

Here is τ – stress tensor (Pa); β – inter-phase momentum exchange coefficient (kg/(m3 s)).

The stress tensor of gas phase is given by

$$\tau_{g,ij} = \mu_g \left(\frac{\partial u_{gj}}{\partial x_i} + \frac{\partial u_{gi}}{\partial x_j} \right) \tag{4}$$

Here is μ – viscosity (Pa s).

Table 1 shows the boundary conditions necessary for the mathematical modeling.

Table 1. The boundary conditions.

Fuel mass flow Bg, kg / s	1.89
Fuel type	anthracite
Excess air ratio	1.2
The diameter of the coal particles, mm	2.5
Excess air ratio	1.2
Air temperature, °C:	
Burners inlet	460
Air nozzles inlet	300
Air velocity, м/s:	
Burners inlet	1.5
Air nozzles inlet	7.7

The study was carried out using the program ANSYS Fluent 12.1.4. For calculation simplication productivity and the two-dimensional computational grid was used (figure 2).

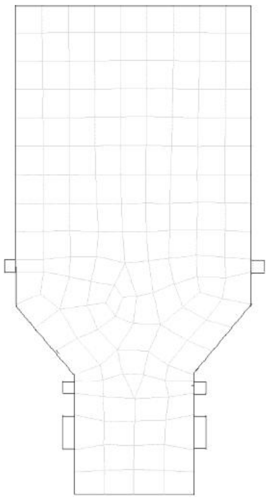


Figure 2. Estimated Net furnace.

3. Results of the study

Figures 3 and 4 show the concentration of fuel particles, fractions of volatilizes and concentration change with the height of the combustion chamber for variants of fuel loading at 1.2m, 2.4m, 4m.

Figures 3,a and b show that when loading the fuel to a height of 1.2 m of the solid phase rate reaches the average value of 0.8m/s. Concentration of the fractions of fuel reaches a maximum value of 0.47. Comparing Figures 3,c and d to Figure 3, it is possible to see that there is output of fuel fractions from a lower portion of the combustion chamber. The average solids velocity is 0.85 m/s.

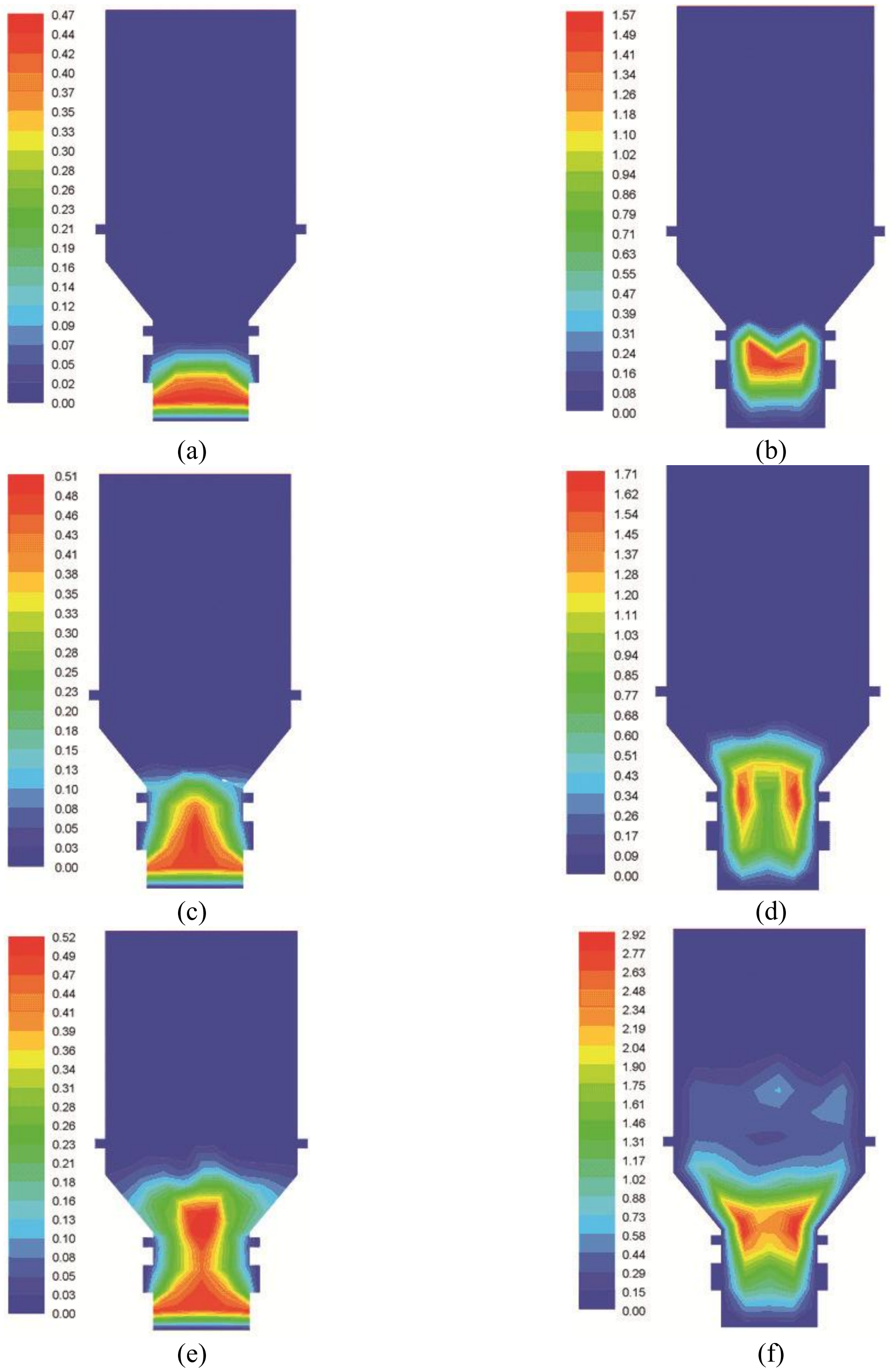
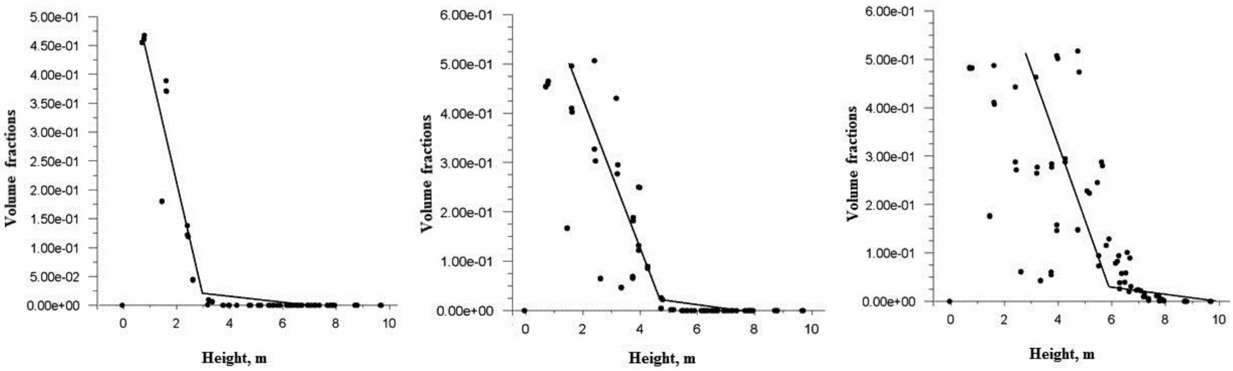


Figure 3. Results of numerical simulation: (a) – the concentration of the fractions of fuel in a fluidized bed when loading fuel at 1.2m; (b) – solids velocity when loading fuel at 1.2m; (c) – the concentration of the fractions of fuel in a fluidized bed when loading fuel at 2.4m; (d) – solids velocity when loading fuel at 2.4m; (e) – the concentration of the fractions of fuel in a fluidized bed when loading fuel at 4m; (f) – solids velocity when loading fuel at 4m.

The most rational pattern can be observed in figures 3,e and f. The highest concentration is focused on the center of the combustion chamber and exposed to air, both below and on the sides of the air nozzles, climbs up the combustion chamber. The maximum speed of the solid phase is observed in the vicinity of the first row of air nozzles and reaches 2.92m/s.



(a) (b) (c)

Figure 4. Change in concentration depending on the altitude: (a) – loading fuel at 1.2m; (b) – loading fuel at 2.4m; (c) – loading fuel at 4m.

According to figure 4 it can be concluded that the more fuel loading, the higher the height distributed fuel fractions. These visual results of a series of numerical modeling parameters investigated were prepared using Eulerian.

4. Conclusion

The most rational pattern is observed when loading the fuel to a height in the range of 2.4 m - 4 m as when loading fuel at a lower height is difficult to draw any conclusions on the dynamic processes. This range allows that race gas dynamic processes in the furnace of a fluidized bed boiler. Theredemolitionfuelfractionsclosertothecenterofthebottomofthecombustionchamberanditssubsequentdistributionadjustment. Speed also remain with in the range limits.

This approach is the study of gas-dynamic processes can rationally exploit the boiler units with circulating fluidized bed.

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