Fluid dynamics simulation for design on sludge drying equipment

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Abstract. Sludge drying equipment is a key component in the sludge drying disposal, the structure of drying equipment directly affects the drying disposal of the sludge, so it is necessary to analyse the performance of the drying equipment with different structure. Fluent software can be very convenient to get the distribution of the flow field and temperature field inside the drying equipment which reflects the performance of the structure. In this paper, the outlet position of the sludge and the shape of the sludge inlet are designed. The geometrical model of the drying equipment is established by using pre-processing software Gambit, and the meshing of the model is carried out. The Eulerian model is used to simulate the flow of each phase and the interaction between them, and the realizable turbulence model is used to simulate the turbulence of each phase. Finally, the simulation results of the scheme are compared and the optimal structure scheme is obtained, the operational requirement is proposed. The CFD theory provides a reliable basis for the drying equipment research and reduces the time and costs of the research.

1. Introduction
At present, the method using cement kilns to co-processing sludge is relatively rare, many devices in common use for sludge drying are general waste treatment equipments [1-4]. The synergetic treatment of sludge in cement kiln will provide a new method for disposal of sludge due to its advantages of harmlessness, resource utilization and stabilization. The extensive sludge disposal methods will be gradually eliminated. And that will lead to more and more intense competition in the equipment research and technology of sludge disposal. FLUENT software can provide considerable help for the research of drying equipment [5-7]. This paper develops a highly efficient mechanical and automated processing device to realize harmless sludge treatment under the guide of fluid dynamics simulation.

2. Structure and mesh
The drying equipment composed of feed inlet, air inlet, outlet, rotating shaft, blade and other components is the core component of the whole sludge disposal process, as shown in Fig1-a. The rotating shaft and blade is used to smash the sludge. High water content sludge enters through the feed inlet, high temperature gas enters through the air inlet, and the outlet discharges the sludge after the drying treatment. The position of the inlet and outlet need to be determined through simulation.
Figure 1. Schematic diagram and grid of the drying equipment

The main size of the drying equipment is as follows: the diameter of the drying equipment is 2000mm, the height is 2850mm; the inlet diameter is 800mm; the outlet diameter is 800mm; the feed inlet is a cylindrical shape with a diameter of 800mm or a square with a width of 200mm; the position of the air inlet and the outlet are not sure. The different geometric models of drying equipment are constructed by FLUENT pre-processing software GAMBIT. In order to make the simulation results more consistent with the actual flow conditions, the drying equipment should be divided into sub-regions, and the grid of each area is shown in Fig1-b. A total of 7200,000 tetrahedral and hexahedral meshes are used to partition the model. After meshing is completed, it’s necessary to check the skew of the mesh. In general, the maximum skew of the grid should be less than 0.95, the average should be below 0.33. When the skew of the grid is higher than 0.95, the calculation result is not easy to converge, and it will affect the accuracy of the simulation results. The grid model of the drying equipment is checked, and the maximum skew of the grid is 0.74, which is lower than 0.95. Therefore, the mesh quality meets the requirements of the calculation, and it has good matching performance.

3. Computational model

3.1. Governing equation

The Euler-Euler model is often used to simulate the flow of multiphase flow and the interaction between the various phases of the multiphase flow [8]. It has good adaptability to the internal flow of the drying equipment. In the analysis, the high-temperature air and sludge flows are treated as continuous flows, each of them is required to follow the mass, momentum and energy equations. The continuity equation is expressed as follow:

$$\frac{\partial \rho}{\partial \tau} + \frac{\partial (\rho u_x)}{\partial x} + \frac{\partial (\rho u_y)}{\partial y} + \frac{\partial (\rho u_z)}{\partial z} = 0$$

(1)

where $\rho$ is the density of the high-temperature gas and sludge, and $u$ is the velocity of each phase. The momentum equation of gas and fluid is:
\[ \rho \frac{d\mathbf{u}}{dt} = \rho \mathbf{F}_b - \nabla p + \mu \nabla^2 \mathbf{u} \]  

(2)

where \( F_b \) is the volume force acting on the fluid system during each phase flow, \( P \) is the pressure, and \( \mu \) is the viscosity coefficient of each phase. The drying of sludge involves heat transfer, and the energy equation of the heat transfer process is:

\[
\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\rho \mathbf{u} (E + P)) = \nabla \cdot \left( \mathbf{k}_{\text{eff}} \nabla T - \sum_h \mathbf{J}_h + \left( \mathbf{b}_{\text{eff}} \cdot \mathbf{v} \right) \right) + S_h
\]  

(3)

Where \( \mathbf{k}_{\text{eff}} \) is effective thermal conductivity; \( \mathbf{J}_j \) is the diffusion flux of component \( j \). The first three terms on the right side of the equal sign indicate the energy transfer due to thermal conductivity, component diffusion, and viscous dissipation. \( S_h \) is the source item, including heat generated by chemical reaction heat and other user-defined volume heat sources.

### 3.2. Turbulence model

In the simulation analysis of CFD, it is necessary to take into account the viscosity of fluid. In this paper, the Reynolds number is calculated to be 5.13e5, so it can be known that the flow inside the drying equipment should be turbulent. The selected turbulence model is the realizable \( k-\varepsilon \) model. And the turbulent kinetic energy \( k \) and the dissipation rate \( \varepsilon \) equations are:

\[
\frac{\partial (\rho k)}{\partial t} + \nabla \cdot (\rho \mathbf{u} k) = \nabla \cdot \left( \mathbf{D}_{tu} \frac{\partial u}{\partial x} \right) + \rho \varepsilon
\]  

(4)

\[
\frac{\partial (\rho \varepsilon)}{\partial t} + \nabla \cdot (\rho \mathbf{u} \varepsilon) = c_1 \rho \varepsilon \frac{\varepsilon}{k} + c_2 \rho \varepsilon^2
\]  

(5)

\( \Phi \) is:

\[
\Phi = \frac{1}{3} \text{arccos} \left( \sqrt{6W} \right)
\]

\[
W = \frac{S_{ij} S_{j,k} S_{k,l}}{(S_{i,j} S_{j,i})^{3/2}}
\]

\( U^* \) is:

\[
U^* = \sqrt{S_{i,j} S_{j,i} + \Omega_{i,j} \Omega_{i,j}}, \quad \Omega_{i,j} = \Omega_{i,j} - 3 \varepsilon_{i,j,k} \omega_k
\]

The constants \( c_1, c_2, \sigma_k, \sigma_\varepsilon \) in those equations have the following default values: 1.44, 1.92, 1.0, 1.3.

### 3.3. Boundary conditions

Boundary conditions are the laws of the time-varying variables in the solution of the flow region. The reasonable boundary condition is very important for the simulation results. In this paper, the high temperature gas inlet and the feed inlet are set to the velocity inlet, the discharge port is set to the pressure outlet. The variables selected for turbulent flow are the hydraulic diameter and the turbulence intensity. The hydraulic diameter should be set according to each import and export, and the turbulence intensity is set to 5%. The boundary conditions are determined as shown in table 1.
Table 1. Boundary conditions

| Attribute            | Feed inlet | Air inlet | Discharge port |
|----------------------|------------|-----------|----------------|
| Boundary type        | velocity-inlet | velocity-inlet | pressure-outlet |
| Velocity/(m/s)       | 18.51      | 18.24     |                |
| Temperature/K        | 371        | 576       | 530            |
| Hydraulic diameter/m | 0.8        | 0.2       | 0.8            |
| Turbulence intensity/%| 5          | 5         | 5              |

4. Simulation and analysis

By means of Fluent software, a series of temperature distribution and velocity distributions are obtained. The flow field inside the drying equipment can be displayed visually.

From Fig 2.a it can be seen that when the air inlet is located under the drying equipment, a large range of low speed area will appear inside the drying equipment. The existence of this region will make the heat exchange between sludge and high-temperature gas inefficient, which is not conducive to the drying of sludge. Fig 2.b tells that when the air inlet is set in the side below the drying equipment, the internal flow field has undergone great changes. The previous low-speed area is reduced a lot, and the overall speed of the material within the equipment improves a lot. Such a promotion for the drying of the sludge is very favorable, it will improve the drying efficiency of the sludge to a certain extent.

Figure 2. The impact of the air inlet and discharge port location
Fig2.c shows that when the material outlet is set on the side of the drying equipment, most of the area inside the drying equipment near the outlet is about 430K. Considering that the dried sludge will enter the cement kiln, this temperature may have some effect on the temperature field inside the cement kiln. It can be seen from Fig2.d that when the material outlet is located above the drying equipment, the internal temperature is raised a lot. Especially in the material outlet area, the temperature of most of the region is around 500K. This is not only conducive to the drying of sludge, but also can reduce the impact on the cement kiln.

5. Conclusion
According to simulation results, the final structure of the drying equipment is: the shape of the feed inlet is square and the size is 200mm; the high-temperature gas inlet is set side below the drying tower; the discharging port and the feed inlet are arranged on the top of the drying equipment tower. After the drying equipment is put into operation, the condition of equipment working is very good and the ability to deal with sludge increased significantly. The capacity of disposal sludge reached 2.5 tons/hour. At the same time, the operating cost of equipment is much lower than other equipments, which brings about a higher economic benefit.

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