Analysis of the Temperature and CO_2 Concentration in Precalciner Based on Fluent Software

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Abstract. The coupling between the pulverized coal combustion and raw meal decomposition in precalciner of the cement plant with capacity of 5000t/d was investigated by Fluent software. The standard k-ε model was proposed to simulate the three-dimension turbulence flow. The multiphase was calculated coupling process. The non-premixed combustion model was applied to the chemical reaction. The energy generated by chemical reaction was expressed the PI radiation model. The particle stochastic trajectory model was abided by track particles movement. The simulate results show the field of temperature and CO_2 concentration with three decomposition ratio 85%, 88% and 92%. This provides the thermal data for the producers and managers in the cement plant.

Introduction

With the development of the cement technology, the cement equipments are upgrading constantly. In recent years, the successful application of the new dry-process precalciner kiln to the cement manufacture accelerates the industrial progress. Precalciner is one of the most important equipments of cement system, there are gas-solid flowing, radiation heat transfers, pulverized coal combustion and raw meal decomposition, in which the raw meal suspended in gas flowing requires the heat generated by burning pulverized coal in order to decompose $CaCO_3$ in raw meal. It has already reported that complex process in precalciner has great effect on energy consumption, pollutants discharge and production efficiency [1,2]. So far, the decomposition ratio is about 85%~95%[3,4]. In this paper, the coupling of pulverized coal combustion and raw meal decomposition is numerical simulated by Fluent software. The temperature and CO_2 Concentration is analyzed. It will provide basis for the structure design and engineering applications of cement precalciner.

Geometrical Model and Generating Grid

Fig.1 is the entity structure of the precalciner in the cement plant with capacity of 5000t/d. Three sections along the axial duct are shrunk. The four pulverized coal burners include two main burner and two assistant burner, which are eccentric, symmetrical and downward at 60° to the axis on two sections. Two tertiary air ducts are eccentric 1280mm into the precalciner. Four feeding boxes without eccentric to the axis are distributed uniformly. The corresponding size is shown in Fig. 2. To simulation numerically, the structure need to be meshed, as shown in Fig.3.

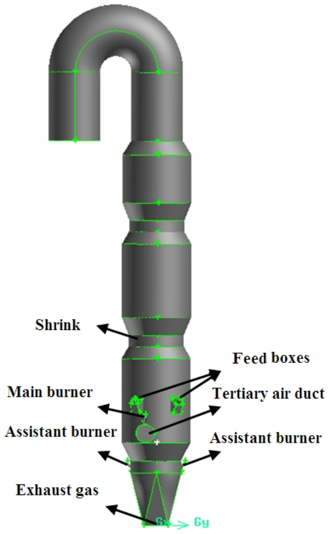

Fig.1 Entity structure of precalciner

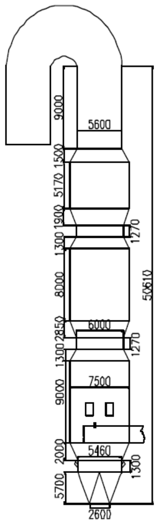
Fig.2 Size of precalciner

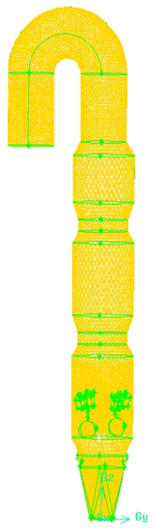
Fig.3 Grid figure of precalciner

Mathematical Simulation Model

Turbulence Model. The gas flow in precalciner is three-dimension turbulent flow and can be regarded as the steady-state flow. The standard k-ε turbulent model is applied to simulate and the control equation can be written as following:

$$\frac{\partial}{\partial x}(\rho u \phi) + \frac{\partial}{\partial y}(\rho v \phi) + \frac{\partial}{\partial z}(\rho w \phi) = \frac{\partial}{\partial x}(\Gamma_\phi \frac{\partial \phi}{\partial x}) + \frac{\partial}{\partial y}(\Gamma_\phi \frac{\partial \phi}{\partial y}) + \frac{\partial}{\partial z}(\Gamma_\phi \frac{\partial \phi}{\partial z}) + S_\phi \tag{1}$$

where, ϕ present the rate of u, v, w, turbulent kinetic energy k and turbulent dissipation rate ε respectively. $S_\o$ is the source term. The list of these symbols can be seen in Ref.[5].

Radiation Model. The energy generated by chemical reaction and radiation represents the energy source terms. The P1 radiation model is used to evaluate the contribution of radiation to the enthalpy equation and calculated from:

$$\frac{dI(\vec{r},\vec{s})}{ds} + (a + \sigma_s) I(\vec{r},\vec{s}) = an^2 \frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\vec{r},\vec{s}\,')\Phi(\vec{s}\cdot\vec{s}\,')d\Omega' \tag{2}$$

Where, $\vec{r}$, $\vec{s}$, $\vec{s}\,'$ presents position vector, direction vector and scattering direction vector, $\boldsymbol{a}$ is absorption coefficient, $\boldsymbol{\sigma_s}$ is scattering coefficient, Φ is phase function, Ω' is solid angle.

Combustion Model. To handle the mean rate of reaction and adequate representation of the chemistry, the non-premixed combustion model is selected[6]. The instantaneous thermochemical state of the fluid related to a conserved scalar quantity, and the mixture fraction f can be written in terms of the atomic mass fraction as

$$f = \frac{Z_i - Z_{i,\mathrm{ox}}}{Z_{i,\mathrm{fuel}} - Z_{i,\mathrm{ox}}} \tag{3}$$

where Z_i is the elemental mass fraction for element, i.

Particle Trajectory Model. In particles movement, the trajectories are tracked by discrete random walk model, and the control equations can be written as following:

$$\frac{d\phi_p}{dt} = F_D(\phi - \phi_p) + \frac{g_i(\rho_p - \rho)}{\rho_p} + F_i \qquad (4)$$

where ρ is particle density, F is additional mass force, F_D is defined as the parameters related to the particle diameter, viscosity coefficient of gas molecules and Reynolds number[7].

Numerical Calculate Process

The boundary values in calculation are determined by the thermal data of cement plant with the capacity of the 5000t/d. Velocity inlet, pressure outlet and standard wall function are selected as boundary conditions. The type of discrete phase on inlet and outlet is defined as escape, and at the walls is set to reflect. The multiphase is used to calculate coupling process and the non-premixed combustion model is applied to calculate internal flow field of temperature and CO_2 concentration. The governing equation is discrete by the control volume method and solved by SIMPLE algorithm and STANDARD on Fluent 6.3 software. The Second Order Upwind is applied after igniting pulverized coal to improve the calculation accuracy.

Simulation Results Analysis

To get a comprehensive explore for coupling process between pulverized coal combustion and raw meal decomposition, the temperature and CO_2 concentration field is given in Fig.4 and Fig.5.

$CaCO_3$, which is the main components in raw meal, can be decomposed to CaO and CO_2 when it is heated more than 1100K. Fig.4(a), Fig.4(b) and Fig.4(c) respectively represent the temperature of raw meal decomposition ratio of 85%, 88% and 92% in precalciner. The inner temperature is nearly between 1190 K and 1700K. There is the higher temperature area in the centre of the main burner area, where presents the coal combustion temperature, from the main burner area to the second shrink along the precalciner axis, the temperature in the case of three decomposition ratio reduce gradually to about 1465K, 1430K and 1390K. Above the second shrink till to the outlet, the temperature distribution is almost uniform in the range of 1200 K. These show that temperature filed is reasonable and provide the advantageous temperature of the raw meal decomposition.

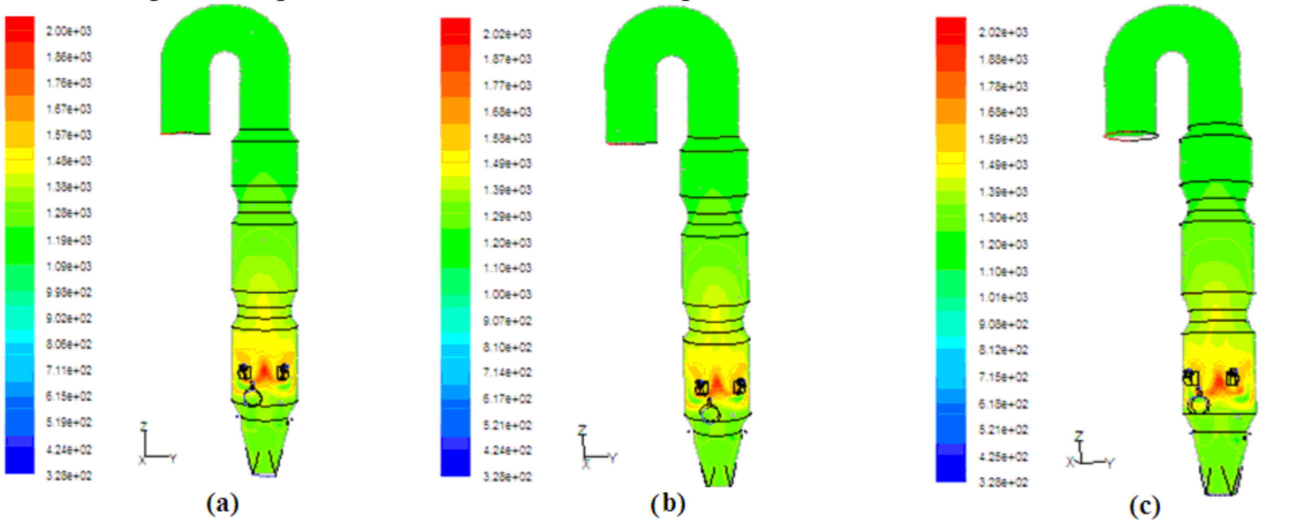

Fig.4 Temperature distribution in raw meal decomposition ratio of (a) 85%, (b) 88% and (c) 92%

Corresponding to the temperature fields in Fig.4, the CO_2 concentration distributions are also given in Fig.5. From Fig.5 (a) to Fig.5(c), the similar trends of the CO_2 concentration with three raw meal decomposition ratios of 85%, 88% and 92% are found. The lower value takes place near main burner area, the increasing is at the shrink section above main burner area, but uniform distribution.

These imply that the raw meals into the precalciner are decomposed instantaneously, and well coupled with the pulverized coal combustion. In feeding box area, the mass fraction of CO_2 is 17.8%, 19.1% and 20.0% respectively. As the $CaCO_3$ reacts continuously along the axis, the corresponding fraction in the outlet increases to 20.1%, 21.0% and 22.3%, which is higher than that in feeding boxes area.

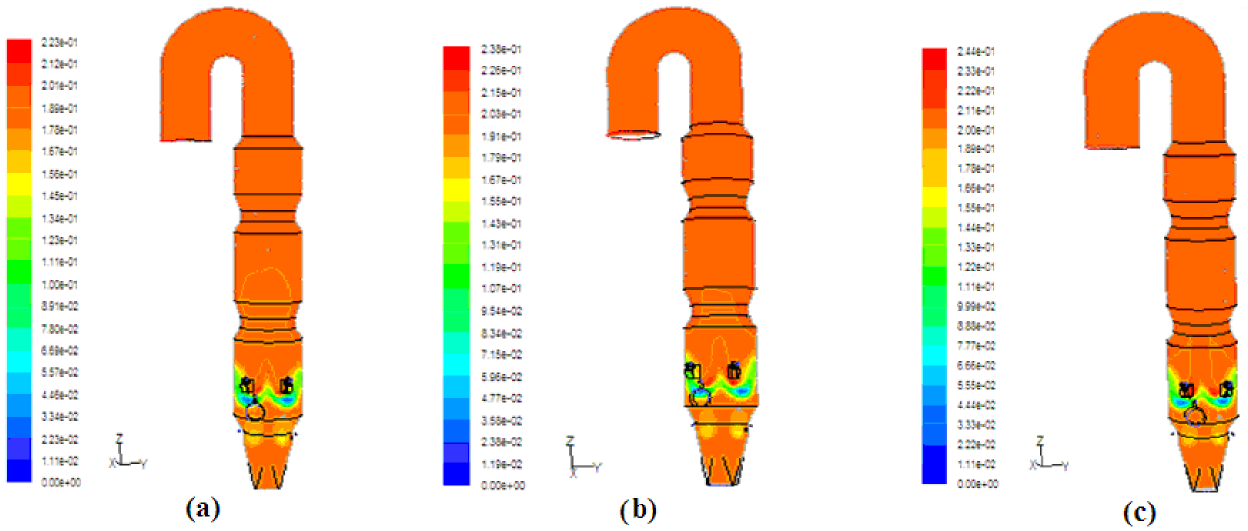

Fig.5 CO_2 concentration in raw meal decomposition ratio of
(a) 85%, (b) 88%, (c) 92%

Conclusions

This paper presented numerical fields of the temperature and the CO_2 concentration when the decomposition ratio is 85%, 88% and 92%. Temperature and CO_2 concentration field are analyzed. The concentration of CO_2 as well as temperature in each decomposition ratio distributes similarly and symmetrically along the axis. The center temperature in shrink above main burner is 1465K, 1430K and 1390K, and the mass fraction of CO_2 in outlet is 20.1%, 21.0% and 22.3% accordingly. This simulate can effectively guide the cement manufacture.

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