A Discussion on Thermal Cycling System Based on Boiler Simulation

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ABSTRACT: *In recent years, coal-fired power units developed in the direction of large-scale, and therefore the simulation system of large-scale firepower unit has been booming. Small unit equipment is facing the problem of aging, inefficient, and therefore will be gradually eliminated. However, due to the actual demand of industry, some small thermoelectric coupling units have been put into operation. Under the comprehensive influence of historical development level and enterprises' overall economic benefit, some small thermoelectric coupling unit operation and maintenance personnel's overall level is not high. Therefore, this paper established a circulating fluidized bed (CFB) boiler simulation system based on XinXiang HG-440 CFB, and analyzed final simulation system. Simulation process from thermal efficiency to thermal energy transformation were researched based on rules of thermal cycling and outlet of improving thermal energy utilization. The result showed that the simulation which is put up in this paper is suitable for the development of the thermal cycling system based on boiler simulation.*

Keywords: Boiler simulation, Thermal cycling, Thermal energy utilization

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1. Introduction

China is a great energy power in the world. It would be not easy for China to develop its economy in a high speed without the support of energy. Energy is the base for economic growth. However, recent years resulting from over-expanding coal and other energy environment in China the conditions get worse and worse day by day, which greatly threatens sustainable development. In order to efficiently guarantee sustainable development of environment, coordinated development of energy production and clean coal technology comes into being consequently [1]. This kind of technology can not only improve the efficiency of the energy, but also can efficiently decrease the inventory of total polluted gases produced in the process of energy combustion. Because of its clean and efficient combustion, circulating fluidized bed boiler was used as power supply device in many modern industries. The control system of CFBB including rum water level control, main steam control and combustion control, and the combustion control are the first and most complicated control link. With the characters of complex variables, long time lag and intense nonlinear, it is very hard to establish the precise combustion control model in the actual industrial process. Otherwise the result of classic PID controller turned to be improper in the parameter setting, bad in performance and poor adaptability in adjusting the change of operation. In addition, it is time-consuming to debugging and setting PID parameters artificially [2] as the technology gets to hot topic in the world. Nevertheless objective experiment of CFB technology often costs too much, which is unfit to process in practice. Therefore CFB simulation takes great advantage in the field [3]. In the present work, a steady state mathematical model of coal fired CFB boiler has been developed, integrating the hydrodynamics, heat transfer and combustion which include the dense zone and dilute region in the furnace. The model predicts the distributions of the gas concentration, chemical species, and temperature and heat flux along the furnace in both the axial and radial locations. The model was validated against experimental data generated in a 35 t/h CFB boiler of low circulation ratio with wide size distributions.

2. Simulation Object

XinXiang HG-440 CFB boiler is the simulation object in this paper. This kind of boiler is produced by Harbin boiler factory integrating German ALSTOM company's EVT technology. It can further optimize coal clean on the condition of high temperature and high pressure. Besides it, this kind of boiler is widely used in daily life and produces more varied types of CFB boilers, such as HG-440 which is a representative figure 1.

The model addressed in this paper is composed of two parts: a combustion system model and steam side model; each is an assembly of many submodels. All of these submodels are based on conservation equations, principal physical laws, physical and chemical process equations and empirical models. The circulating loop model includes the following submodels: combustion chamber model, cyclone model, standpipe model and ash cooler model. The principal part of the model is a series of conservation equations [4]. To guarantee precision and reliability for engineering analysis, a cell model scheme is adopted to simulate gas/solid flow along the axis, meanwhile, a core/annulus flow structure is used to simulate particle distribution asymmetry along the radial direction in the combustion system. Furthermore, the wide size distribution of feed and in bed materials is also taken into account. The core/annulus flow structure has been demonstrated and commonly accepted by many investigators. The annular (wall region) is characterized by sheets or streamers or falling particles interspersed with periods where there is a dilute upward-moving solid suspension. Typical voidages of the streamers are in the range of 0.6–0.8

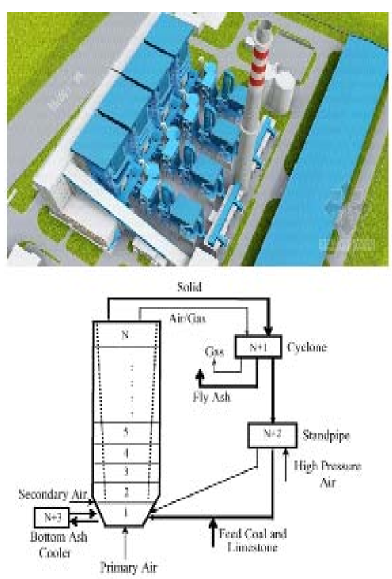

Figure 1. Typical cell configuration of CFB boiler simulation

3. Simulation and Digital Model of CFB Boiler

In the combustion process of CFB, boiler qualities of its intrinsic energy and power energy is produced to observe the law of conservation of mass. So the mathematical the model of CFB boiler has been established to include all kinds of energy conservation, such as solid and gas. Mass conservation of energy becomes the base to build boiler model. Mathematical model of CFB boiler consists various sub-models. Analyzing of sub-models is as follows.

3.1 Boiler Components Model

The most important part in designing CFB boiler is to design a separating device. In practical working, cyclone separator is the most common separating device. When cyclone separator works, energy stream of gas and solid in its inner part is an extremely complex and magnified process (See figure 2).

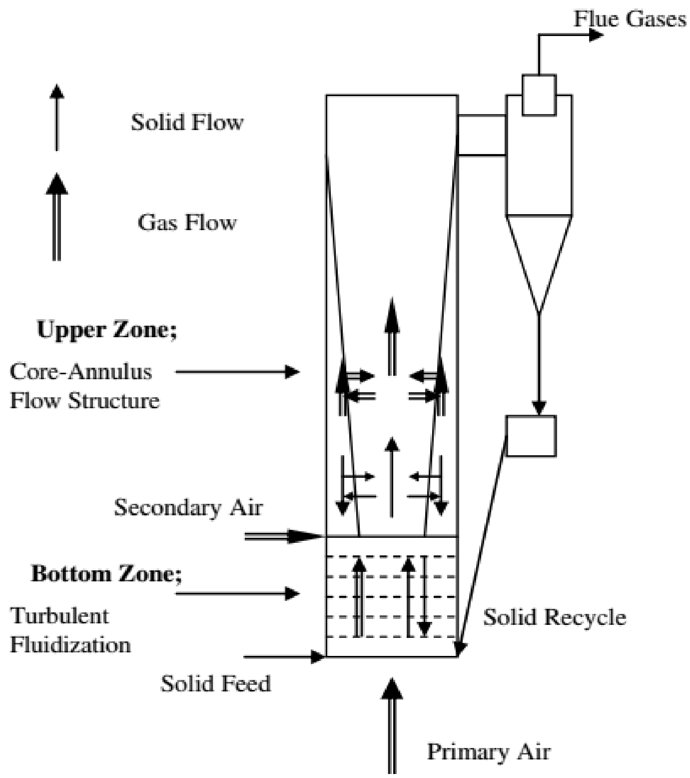

Figure 2. The scheme of the CFB

In order to easily express it, this paper assumes when energy existing as gas exercises in separator its trajectory could be seen as the same area among slug stream and along with gas energy. The cross selection of separator entrance ignors coal particle's vertical disintegrating in the process of rotating with gas, and it only happens at the bottom of gas stream in the process of vertical disintegrating [5]. In addition, in this assumption it should also ignore slip velocity and other shear forcing to gas and solid, which is only considered to cross section area of separator entrance. Through simplifying practical condition material balance of coal particles in separator can be gained as following:

$$\frac{d(VpiCi)}{dI} = Dspi\ \frac{d2Ci}{dI2} + Gspi \tag{1}$$

Among them *Ci* stands for permeation flux of coal particles *i*; *Vpi* stands for the velocity of coal particles; *Dspi* stands for vertical disintegration models of coal particles; *Gspi* stands for the production rate of coal particles; *I* stands for the height when gas spires along separator.

3.2 Combustion Model of Coal Particles

Combustion of coal particles is a complex process which constantly happens chemical change and energy change, especially in CFB boiler. In order to have a better research the combustion process coal particles into CFN boiler can be summarized as: particles go into the inner part of CFB boiler, then dry coal particles, and further exhaust all kinds of volatile compounds in coal particles. Moreover combustion coal particles, finally process the post-combustion of rest coal particles[6].

In order to explain coal particles in the process of its combustion, assumption is needed: carbon monoxide and carbon dioxide both belong to the production of primary combustion in the process of coal particles' combustion[7]. Carbon monoxide will stay in the furnace in primary combustion. As for different ash coal particles, they can be generally divided into three types: high ash particles, low ash particles and aerosol coal particles. They exist in the forms of double-retract, retract and none- retract in combustion [8].

In the process of coal particle combustion, in order to explain the gas coming during combustion in CFB boiler, an assumption is needed: as for different volatile contents in coal particles combustion, it only needs to be represented as one volatile content; Chemical reaction among varied gases is only controlled by dynamic stress in furnace, then calculation formula for coal particles firing in CFB boiler can be gained as:

$$Ks = \frac{Fs \,.\, CO_2, \infty}{1/K_c + 1/\beta_0 \,.\, (R/R_1)^2 + R/R_1 \,.\, \delta/D_K} \tag{2}$$

3.3 Thermal Model of CFB Boiler

CFB boiler is affected by furnace heating surface area thermal conductivity, material of furnace heating surface, and shape of furnace heating surface in combustion. At the same time it relates the flow velocity of coal particles in furnace, density of coal particles and size of coal particles. Compared with data collected from practical life, data through calculating furnace heating surface modules in combustion, has a range of error within ±5% [9]. As a result, it is relatively reasonable to apply CFB in practical life. So this kind of heat transfer in furnace has been successfully applied to practical production [10].

Heat transfer between fluidized bed and furnace internal wall processes through spiral gas in fluidized bed and impure coal particles together with energy transfer in furnace internal wall. Energy exchange can be divided into convection and scattering after the mixture of gas and material in furnace internal wall [11]. Thereby, the total energy of heat transfer in CFB and linear sum of convection and scattering can be represented as:

$$\begin{aligned} \gamma_b &= \gamma_r + \gamma_c \\ \gamma_r &= \varepsilon\sigma(T_b + T_w)\cdot(T_b^2 + T_w{}^2) \\ \gamma_c &= \gamma_{gc} + \gamma_{pc} \end{aligned} \tag{3}$$

4. Analysis of CFB Combustion System Module

4.1 Mass Balance of Gas and Solid Energy

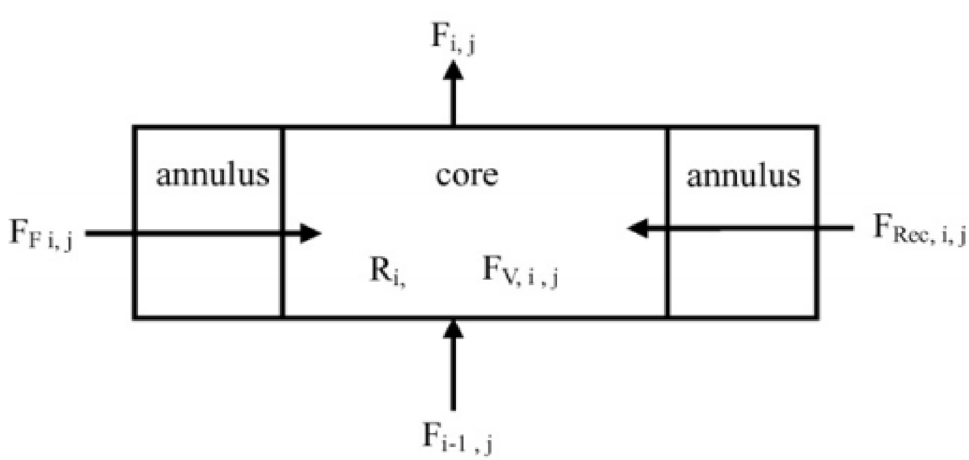

Figure 3. Mass balance of gas and solid Energy

In interior combustion system gas would not disappear assuming its interior part is tight. Value for energy transfer is the sum of convection and scattering energy in steady CFB interior combustion system [12]. Mass balances are made for volatile gases, carbon monoxide, carbon dioxide, oxygen, sulfur dioxide, nitric oxide, nitrogen and water in the core within the fast bed region and in the turbulent zone (bottom region). The classification of solid particles has been discussed and the physical/chemical characteristics of the particles are considered. Furthermore, a mass balance equation is formulated [13]. The mass interchange of size class particles between core and annulus for a given cell is illustrated. In core/annulus flow structure, the thickness of the annulus is very small, so the feed coal, limestone and recycling ash can be assumed to enter the core region directly and they are only considered in the balance equation of the core region [14]. The flow rate of solid particles transmitted from the core to annulus is proportional to the product of the concentration of solids in the core and the interfacial area between the core and annulus regions (See figure 3), while the flow rate of solid particles from the annulus to core is ignored [15].

4.2 Simulation of CFB Combustion System

This paper simulates the effect of different air concentration having on CFB combustion.CFB furnace combustion areas and CFB furnace separator in CFB combustion by designing HG-440 model, through which CFB combustion can be clearly and straightly observed and it contributes to promoting CFB simulation research[16]. To avoid complex calculations with differential integration in the axial direction, the primary loop of a CFB combustor is broken down into cells. These cells are homogeneous, and fully mixed sections. The cell model scheme simply expresses the primary loop of the CFB system and reflects the rapid fluidizing process and principal behaviors of the combustion system such as elutriation (See figure 4), back mixing, mass interchange between core and annulus and gas plug flow in the furnace [17].

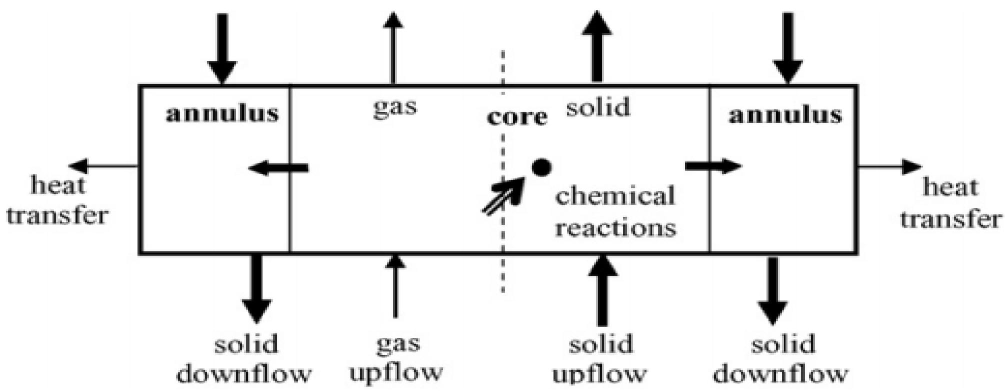

Figure 4. Typical cell configuration

5. Conclusion

As a kind of low energy consumption and low coal consumption technology which rises rapidly in recent years, CFB has been widely used in heavy industry, such as electric power industry and thermal power industry, and made great progress because of its unique advantage. This paper aims to implant new thoughts in designing simulation through analyzing and designing the model in CFB combustion as well as simulating CFB combustion process.

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