A Study and Simulation on Thermal Cycling System of CFB Boiler

Yingtao Hou
State Grid Jibei Electric Power Company Limite
Skills Training Center
Baoding Electric Power VOC.& TECH. College
Baoding, China
E-mail: huangt410128@yeah.net

Xiuhua Jiang
State Grid Jibei Electric Power Company Limited
Skills Training Center
Baoding Electric Power VOC.& TECH. College
Baoding, China
E-mail: jiangxiuhua54322@126.com

***Abstract*—Energy is the main resource for our country to survive. However, in recent years, the excessive consumption of energy has made the environment worse and worse, and made the development of our country restricted. Technology of circulating fluid-bed boiler is the main way of general clean coal at present, and is a hot topic for each country in the world. However, the experimental process of the technology often spend a great cost, therefore is not suitable in practice. So simulation technology of circulating fluid-bed was used in this paper to solve practical problems. This paper established a circulating fluid-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.This technology can not only improved the efficiency of energy, but also effectively reduced the energy generated in the process of burning gas pollution. Moreover, it has played an important role in China's energy construction.**

Keywords-Thermal cycling; Heat transfer model; Thermal energy utilization; Cyclone separator; CFB boiler.

I. 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 gets 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 clean coal technology comes into being consequently. This kind of technology not only improves the efficiency of energy, but also efficiently decreases inventory of total polluted gases produced in the process of energy combustion. As the main technology gets to hot topic in the world CFB 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[1-2].

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.

II. THERMAL MODEL OF CFB BOILER

In the combustion process of CFB boiler qualities of its intrinsic energy and power energy produces both observe law of conservation of mass. So mathematical model of CFB boiler which has been established includes 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 in various sub-models. Analyzing of sub-models is as following.

A. Boiler Components Model

The most important part in designing CFB boiler is to design 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. 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 along with gas energy and cross selection of separator entrance ignoring coal particle's vertical disintegrating in the process of rotating with gas, namely it only happens at the bottom of gas stream in the process of vertical disintegrating. In addition, in this assumption it should also ignore slip velocity and other shear forcing to gas and solid, which' s 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.

B. Combustion Model of Coal Particles

Combustion of coal particles is a complex process which constantly happens chemical change 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, further exhaust all kind of volatile compounds in coal particles, moreover combustion coal particles, finally process post-combustion of rest coal particles[3].

In order to explain coal particles in the process of its its combustion assumption is needed: carbon monoxide and carbon dioxide both belong to production of primary combustion in the process of coal particles' combustion. 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.

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:

$$Ks = \frac{Fs \cdot CO_2, \infty}{\frac{1}{Kc} + \frac{1}{\beta_0} \cdot \left(\frac{R}{R_1} \right)^2 + \frac{R}{R_1} \cdot \frac{\delta}{D_K}} \tag{2}$$

Among them, Fs stands for ratio between carbon content and oxygen content in coal particles' overall reaction; CO2 and ∞ stand for oxygen concentration in pretty far area; K3 stands for carbon combustion rate in coal particles; R stands for radius of coal particles; R1 stands for radius of coal particles post- combustion; δ stands for ash thickness of coal particles; Kc stands for chemical reaction's rate in coal particles combustion; β0 stands for quality motion modules when fluid and furnace happens in coal particles combustion; Dx stands for oxygen diffusion coefficient[4-5].

C. *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 to 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, range of error within ±5%. As a result, it's relatively reasonable to apply CFB in practical life. So this kind of heat transfer in furnace has been successfully applied to practical production[6].

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. Thereby, total energy of heat transfer in CFB and linear sum of convection and scattering can be represented as:

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

Among them γ_r stands for scattering heat transfer modules of coal particles; γ_c stands for convection heat transfer modules; ε stands for system emissivity of fluidized bed and furnace internal wall; σ stands for Boltzmann costant; γ_{gc} stands for smoke convection energy transfer modules after coal particles combustion; γ_{pc} stands for convection energy transfer modules in coal particles combustion.

III. ANALYSIS OF CFB COMBUSTION SYSTEM MODULE

A. *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.

The detailed information of configuration and operation procedures for the 30 kW CFB combustor had been reported in previous publications elsewhere as shown in Fig .1.

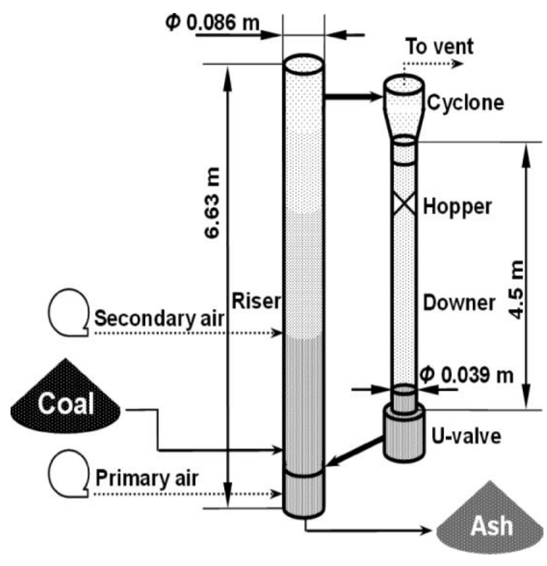

Figure 1. Schematic illustration of a 30 kW circulating fluidized bed combustor

B. *Simulation of CFB Combustion System*

This paper simulates the effect of different air concentration having on CFB combustion., CFB furnace combustion ares 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.

The calculated voidage profile along the CFB riser height in the 30 kW CFB combustor is illustrated in Fig. 2. The voidage in turbulent region 1 is considered as the same as that in turbulent region 2, and the average voidage in acceleration region 3,acceleration region 4, and completely fluidized region 5 is assigned to be equal to that at an appropriate height hi (i= 3, 4, 5) in each region, respectively.The constructed flow sheet of CFB coal combustion process is illustrated in Fig. 3.based on Aspen Plus.

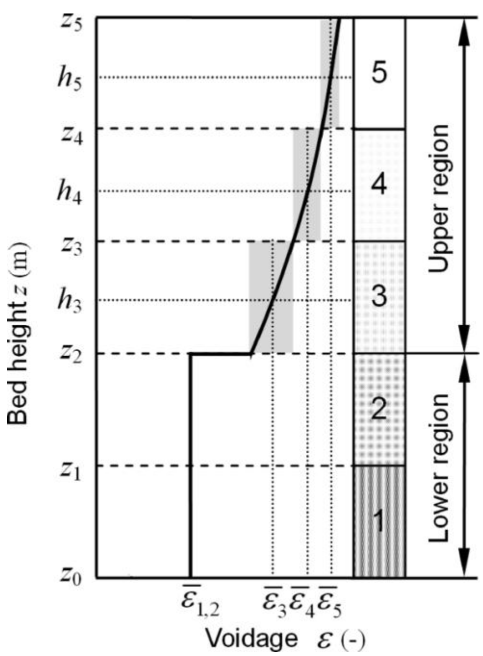

Figure 2. Schematic illustration of relationship between voidage and height in five different subunits along CFB riser height in a 30 kW CFB combustor.

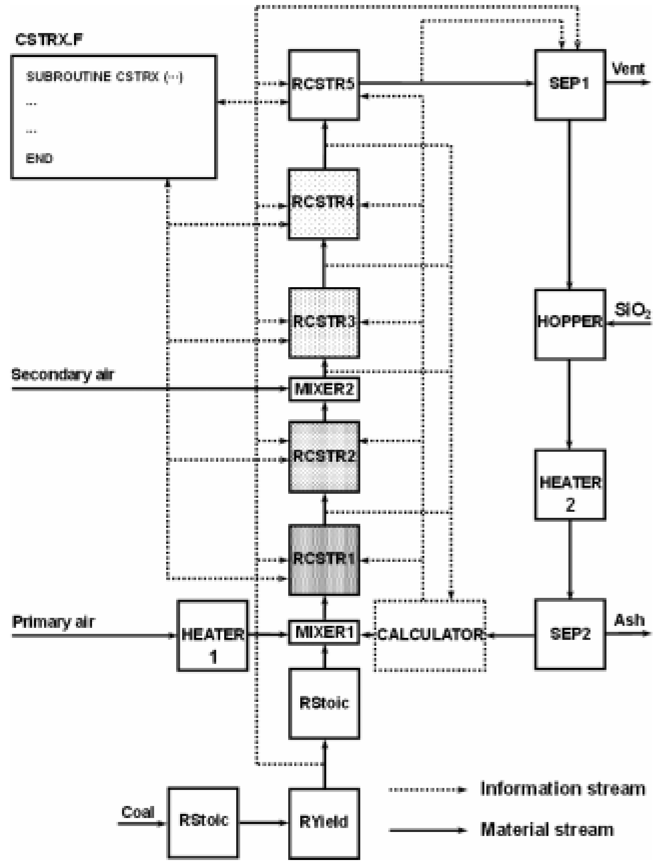

Figure 3. Constructed flow sheet of CFB coal combustion process based on Aspen Plus.

The thermal cycling test parameters were shown in table I.

TABLE I. INITIAL VALUES OF RELATED PARAMETERS IN EACH MODULE FOR SIMULATION OF CFB COAL COMBUSTION BY ASPEN PLUS

upper cycling temperature	temperature changing rates (℃/min)	cycle times
200	5	1
200	5	3
200	5	6
200	5	9

IV. THERMAL CYCLING BEHAVIORS

A. *Thermal Cycling Curves*

The shapes and sizes of the hysteresis loop and the dimensional stability of materials had a direct relationship. The dimensional stability of the material became better when the hysteresis loop was narrow and the area was large; By contrast, the dimensional stability became worse when the hysteresis loop was wide and the area was large during deformation.The diagrams of the relatively linear length variations versus times were shown in Fig. 4. The obvious serrated phenomenon did not see from Fig. 4. The net change in size almost maintained a certain amount after the thermal cycling. It was indicated that the symmetry of stress relaxation was very good in the thermal cycle process.

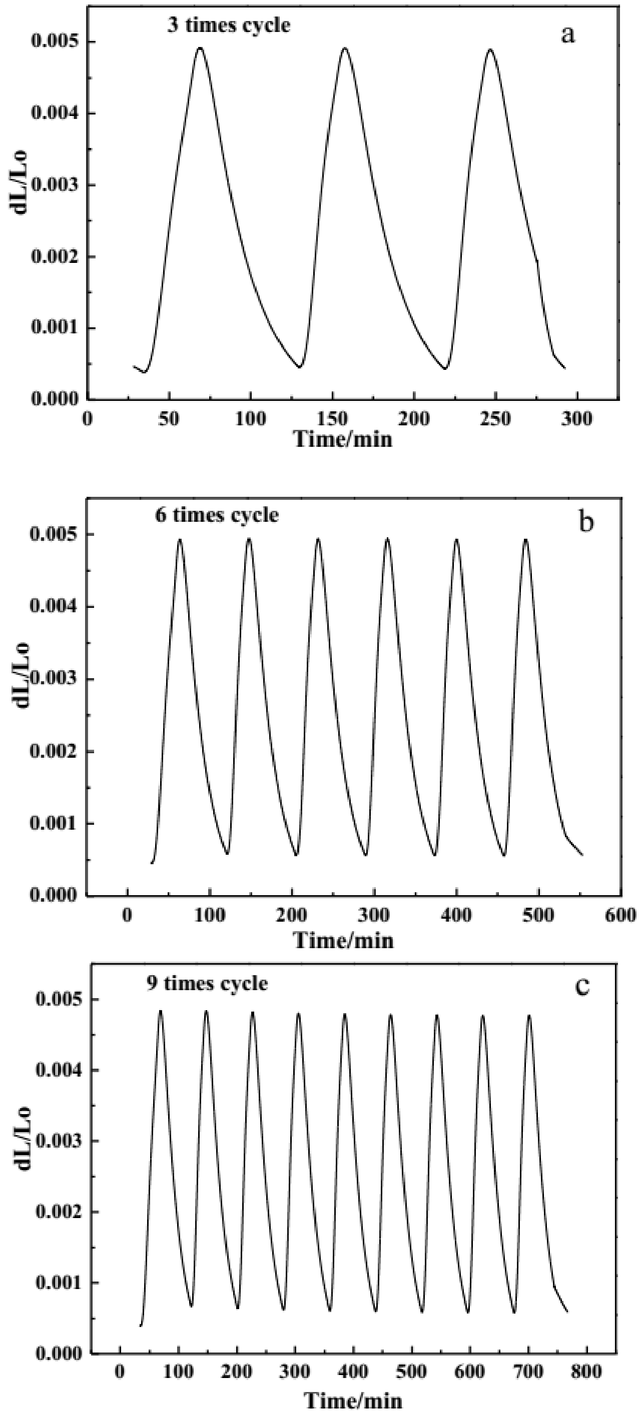

Figure 4. The diagrams of the relatively linear length variations versus times:(a) 3 Thermal cycles (b) 6 Thermal cycles (c) 9 Thermal cycles

The above curves of the relatively linear length variation versus time were converted into the relatively linear length variation versus temperature in order to make it easier to analyze.

The warming and cooling stages during the thermal cycling were distinguished by NETZSCH Proteus Thermal Analysis software and shown in Fig. 5. From Fig. 5 it can be observed that the relatively linear length variations of the warming stage were smaller than the cooling stage.

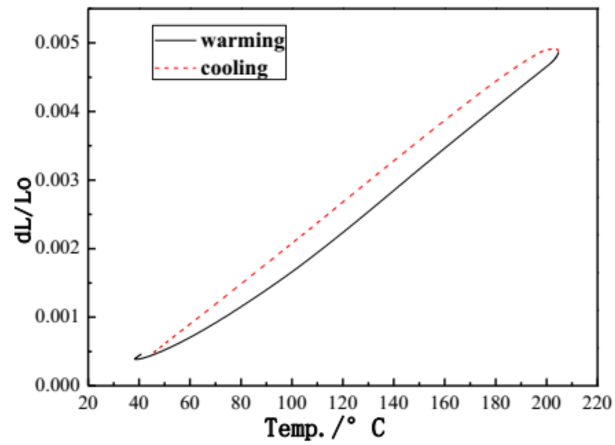

Figure 5. The diagram of the thermal cycling process

B. *The Coefficient of Thermal Expansion*

The CTE-T curves of the 1st, 3rd, 6th warming stages were shown in Fig. 6. It can be seen that the coefficient of the thermal expansion during the first warming stage was significantly larger than the later several warming stages, and the coefficient of the expansion during the later warming stages were basically the same as. This explains the reason that the hysteresis loops of the first warming stage is higher than that of the later warming stages.

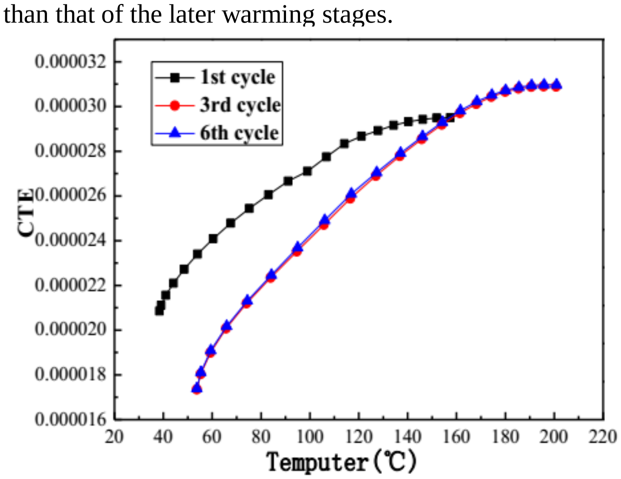

Figure 6. Curve coefficient of thermal expansion

V. 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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