Modelling and Simulation of the 50 MWe CFBC Boiler

Weidou Ni, Zheng Li
Department of Thermal Engineering, Tsinghua University, Beijing 100084, China

A general mathematical model of CFBC boiler by taking the 50 MWe Tsinghua CFBC boiler as the object is established. The model has some distinguished features. Firstly, in order to describe the CFBC precisely, emphasis is paid to take the broad size distribution of feeding coal and bed inventory into consideration. Secondly, the employing of cell model makes it possible to show the distribution of any interested variable inside furnace. Thirdly, since partial aspects such as hydrodynamics, devolatilization of coal, combustion of char and the formation and reduction of harmful substances are considered in detail, therefore the emission at the outlet of the furnace can be estimated. By using the model, simulation is carried out to predict the performance of the 50 MWe Tsinghua CFBC boiler for both design and off-design operation. The results are useful for designers and possible improvement of design.

Keywords: mathematical model, broad size distribution, emission estimation.

INTRODUCTION

Circulating fluidized bed combustion (CFBC) has been paid more and more attention all over the world due to its flexibility to different sorts of fuel, high combustion efficiency and above all, its unique feature of environment protection. However, compared with conventional pulverizing coal combustion boiler, the process taking place inside CFBC is more complicated and people know less about its characteristics. Under such conditions, the modelling and simulation of CFBC boiler becomes a very useful and economical way for a profound understanding of the behaviour of CFBC boiler, the prediction of its performance before manufacturing and providing with advices and guides for the design and future operation, especially for that of control systems.

The Department of Thermal Engineering of Tsinghua University, Beijing, has been long engaged in the research of FBC technology and the research of CFBC since 1984 and has made some achievements. Recently the Department has undertaken the state key project of the eighth five-year plan—the development of a CFBC boiler with a steam generating capacity of 220 t/h (50 MWel), which will be the first large scale domestic CFBC boiler of China.

The modelling and simulation of a 50 MWe is a part of the above mentioned project which aims at the prediction of the performance, the study of the control strategy and providing guides for optimal operation of the 50 MWe Tsinghua CFBC boiler.

THE 50 MWe TSINGHUA CFBC BOILER

The 50 MWe Tsinghua CFBC boiler has some distinguished features. Firstly, it is an internal circulating type CFBC with a built-in auxiliary combustion chamber. Secondly, instead of a huge cyclone, a Tsinghua patent combined planar flow separator is used which keeps the whole boiler compact and in traditional shape. Thirdly, coal with broad size distribution (0~10 mm) is used as the fuel. Finally, it is a CFBC boiler with very low solid concentration and solid loading rate in freeboard.

MODELLING OF THE CFBC BOILER

The whole model includes the modelling of the components of the main combustion chamber, the separator and the auxiliary combustion chamber. In the model, partial aspects such as hydrodynamics, devolatilization of coal, combustion of char, the formation and reduction of harmful substances and heat
transfer are considered in detail. In order to take into account of the broad size distribution of the feeding coal and the bed inventory, the solid particles are divided into a certain number of size groups (represented with \( N \)) and considered separately in hydrodynamics and reactions. An overview of the simulation model of the CFBC boiler is shown in Fig 1.

**Simulation Model of a CFBC Boiler**

**Components:**
- Main combustion chamber
- Auxiliary combustion chamber

**Submodels:**
- Hydrodynamics
- Devolatilization of coal
- Combustion of residual char
- Formation and reduction of CO, SO\(_2\), NO
- Heat and mass transfer
- Cell model with:
  1. mass balance of gas components (O\(_2\), Volatile, CO, CO\(_2\), SO\(_2\), NO, N\(_2\), H\(_2\)O)
  2. mass balance of \( N \) groups of solid particles
  3. mass balance of \( N \) groups of char particles
  4. total energy balance

Fig.1 An overview of the simulation model of a CFBC boiler

The cell model is used as the way for the balancing of substances and energy. For the simulation of the 50 MWe Tsinghua CFBC boiler, the division of... is shown in Fig.2. Considering the height of the dense bed is changing under different operation conditions, the model is designed to be capable of calculating the height of the dense bed and adjusting the height of corresponding cells automatically.

**SUBMODELS FOR THE SIMULATION OF THE 50 MWe TSINGHUA CFBC BOILER**

The model of Rhodes and Geldart (1987) is used to describe the axial flow structure inside the CFBC boiler. In the model, there is a dense bed at the bottom and a dilute phase in the upper part of the furnace. The upwards solid flux at height \( h \) above the dense bed is regarded as a function of \( h \) (Wen and Chen 1982), i.e.:

\[
E(h) = E_\infty + (E_0 - E_\infty)e^{-ah}
\]

In order to take the broad size distribution of bed inventory into account, the solid particles are divided into \( N \) diameter groups. Therefore, the total solid flux at \( h = 0 \) and \( h > TDH \) are:

\[
E_0 = \sum_{i=1}^{N} E_0(i)\text{Bed}(i)
\]

\[
E_\infty = \sum_{i=1}^{N} E_\infty(i)\text{Bed}(i)
\]

here, \( \text{Bed}(i) \) is the mass fraction of particle group \( i \) in the dense bed.

A total mass balance of the CFBC system is set up for the determination of \( \text{Bed}(i) \) (see Fig.3):

\[
W_{Fa,i} - FL_i - D = 0
\]

where, \( W_{Fa,i} \) is the ash feeding rate, \( FL_i \) is the flow rate of flying ash that can not be captured by separator and \( D_i \) is the ash removal rate of particle group \( i \) respectively. \( \text{Bed}(i) \) can be obtained by transforming the above equation and using some other constraints.