

# Simulation of one-dimensional heat transfer system based on the blended coal combustion

Y G Jin<sup>1,2\*</sup>, W B Li<sup>1,2</sup>, Z S Cheng<sup>1,2</sup>, J W Cheng<sup>1,2</sup> and Y liu<sup>1,2</sup>

<sup>1</sup>State Key Laboratory of Automotive Simulation and Control, Jilin University, Changchun 130022, China

<sup>2</sup>College of Automotive Engineering, Jilin University, Changchun, 130022, China

\*E-mail: 694833871@qq.com

**Abstract.** In this paper, the supercritical boiler thermodynamic calculation model is studied. Three types of heat exchangers are proposed, namely furnace (total radiation type), semi-radiation and convection, and discussed. Two cases were simulated - mixing of two bituminous coals and mixing of a bituminous coal and lignite- order to analyze the performance on the flue gas side. The study shows that the influence of flue air leakage and gas distribution coefficient on the system.

## 1. Introduction

Domestic coal production has declined since 2013, while the consumption of coal resources has risen slightly. Coal accounts for more than 60% of the total energy consumption in China, and power generation plants account for about 50% of the total domestic coal consumption [1]. However, while bituminous coal and anthracite - extraction did not grow, lignite and peat production increased [2]. The earliest report about coal blending was in the 1960s, and the early coal blending research was mainly used in coking industry [3]. Chen and Lin used the mass unit matrix analytical method, regarding the actual power plant thermodynamic system as a series of steam and water mixed heat systems. Each part of the power plant is decomposed into condenser parts and heating parts, which establishes an overall equation which has to be solved. Based on this, a mass cell method for heat exchanger based on the distribution equation of heating circulating steam/water is established [4].

Auray *et al* used a combination of linear and nonlinear constraints to determine the optimum coal blending ratio [5]. Shi applied the Cybersim simulation platform (North China Electric Power University) to design and calculate the simulation model of a 660 MW supercritical boiler [6].

Gan *et al* took coal species from specific regions as the research target, using mixed coal element analysis, industry analysis and the calorific value of the raw material [7].

## 2. Thermal system boundary condition

We direct our analysis to the boiler flue gas flow simulation based on the 660 MW supercritical boiler, which is a one-dimensional model. The process includes furnace, low-temperature superheater, final superheater, screen superheater, platen superheater, high-temperature superheater, high-temperature reheater, and low-temperature reheater. Model inputs include different kinds of coal. The boiler flue is arranged in a way of PI (II), which is the most commonly used power plant boiler arrangement. The first vertical section is the furnace, which produces vertical upward smoke. Superheater and reheater are arranged in the horizontal component. The second vertical section is the flue, which includes



economizer and air preheater.

In table 1 the main information of the boiler is presented, while in table 2 the ultimate analysis of the design coal and lignite are shown. The coal blend was obtained from 80% design coal and 20% lignite. Table 3 shows the ultimate analysis of blended coal, which was used as the numerical one-dimensional heat transfer system input.

**Table 1.** Boiler information.

|   |   |
|---|---|
| Furnace volume 18705 m <sup>3</sup>           | Horizontal section of the furnace 342 m <sup>2</sup>  |
| Low-temperature superheater 29 MPa            | Total heating area of the furnace 7944 m <sup>2</sup> |
| Final superheater 28 MPa                      | Screen superheater 28.7 MPa                           |
| Platen superheater 3374 m <sup>2</sup>        | High-temperature superheater 2989 m <sup>2</sup>      |
| High-temperature reheater 4175 m <sup>2</sup> | Low-temperature reheater 114.3 mm                     |
| High-temperature reheater 228.6 mm            | BMCR main steam flow: 2150 t/h                        |

**Table 2.** Fuel properties (ultimate analysis).

| Element  | Design coal | Lignite | Element      | Design coal | Lignite |
|----------|-------------|---------|--------------|-------------|---------|
| $C_{ar}$ | 58.85       | 50.38   | $A_{ar}$     | 19.66       | 5.67    |
| $H_{ar}$ | 3.76        | 2.45    | $M_t$        | 7.7         | 26.8    |
| $O_{ar}$ | 8.43        | 13.17   | $V_{daf}$    | 39.69       | 48.03   |
| $N_{ar}$ | 0.56        | 1.12    | $Q_{net,ar}$ | 22.83       | 17.54   |
| $S_{ar}$ | 1.03        | 0.38    |              |             |         |

**Table 3.** Ultimate analysis of blended coal.

| Element | $C_{ar}$ | $H_{ar}$ | $O_{ar}$ | $N_{ar}$ | $S_{ar}$ | $A_{ar}$ | $M_t$ | $V_{daf}$ | $Q_{net,ar}$ |
|---------|----------|----------|----------|----------|----------|----------|-------|-----------|--------------|
| Data    | 57.15    | 3.499    | 9.379    | 0.6733   | 0.9001   | 16.86    | 11.52 | 41.358    | 21.77        |

The design coal of the boiler and lignite were mixed. For the boiler stable operation, lignite ratio should not be too large, so we put the proportion of lignite 20%.

### 3. Mathematical model and thermodynamic system model

For flue gas flows to tube transversely, it is forced convection and it can be calculated by press type:

$$K = \frac{\psi}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2}} = \frac{\psi \alpha_1}{1 + \alpha_1 / \alpha_2} \quad (1)$$

In the formula,  $\psi$  is the coefficient of thermal effectiveness,  $\alpha_1$  is flue gas side heat transfer coefficient,  $W/(m^2 \cdot ^\circ C)$ ;  $\alpha_2$  is steam side heat transfer coefficient,  $W/(m^2 \cdot ^\circ C)$ .

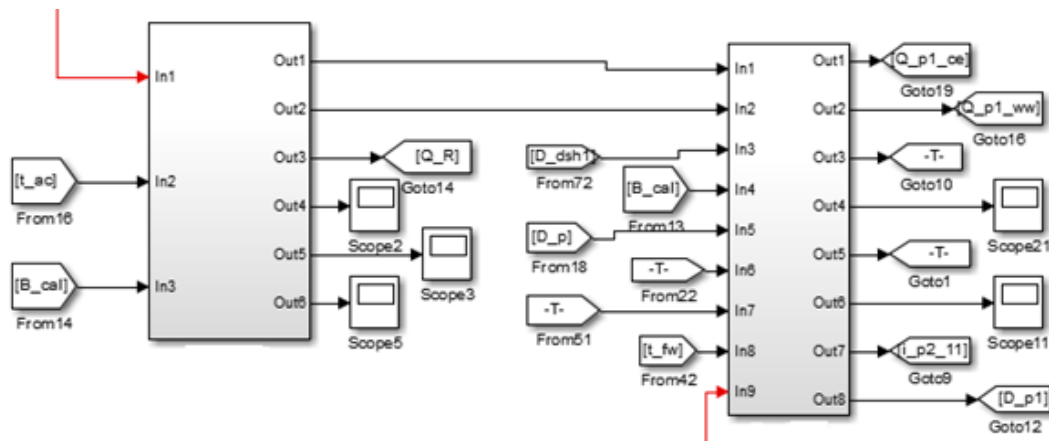
$$\psi = 1 - \frac{\varepsilon \alpha_1}{1 + \left( \varepsilon + \frac{1}{\alpha_2} \right) \alpha_1} \quad (2)$$

According to heat transfer formula

$$q = K(T_1 - T_2) \quad (3)$$

In the case of known heat flow  $q$ , the coefficient of heat transfer  $K$ , inlet temperature of heat exchanger  $T_1$ , we can calculate the heat exchanger outlet temperature  $T_2$ , thus the heat transfer model of the thermodynamic system is established [8].

According to the smoke flow, the block diagram of thermodynamic calculation is divided as shown in figure 1, as a one-dimensional model of the thermal system based on the MATLAB SIMULINK module. The flue gas flow is not connected in series. The flue gas of the two processes is finally aggregated and flows through two air preheating units, to complete the whole flue gas flow. The whole model is too huge to fit the paper, so I select part of the whole. There are many parameters for the inlet and outlet, so we select the signal transmission module as [A] > From and [A] Goto to simplify the model. The red line is connected to the Memory module to achieve the purpose of the early assignment.

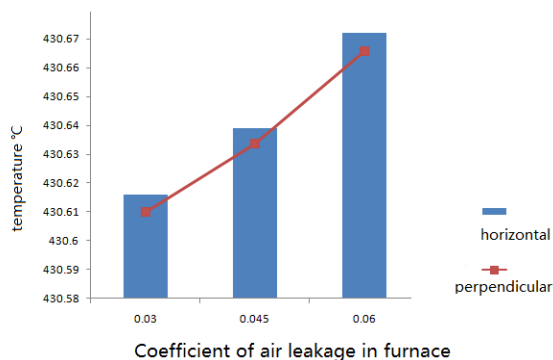


**Figure 1.** Thermodynamic system model (part of whole).

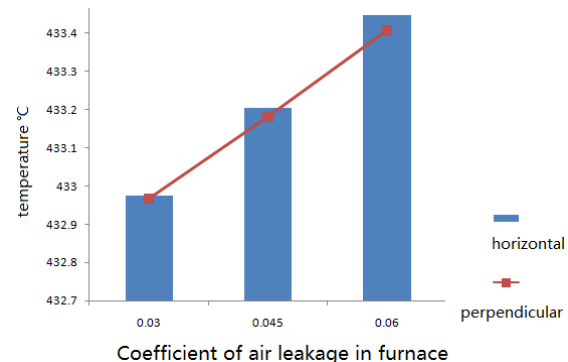
## 4. Simulation results and discussion

### 4.1. Influence of furnace air leakage on system

Since negative pressure boiler flue air leakage is known to reduce the boiler efficiency, an appropriate selection of the boiler leakage coefficient is important. With an increase in the flue gas temperature, leakage of the furnace and flue gas flow rate, the heat transfer coefficient of the flue gas will increase, which will lead to a rise in the steam temperature.



**Figure 2.** Temperature changes of the low-temperature superheater.

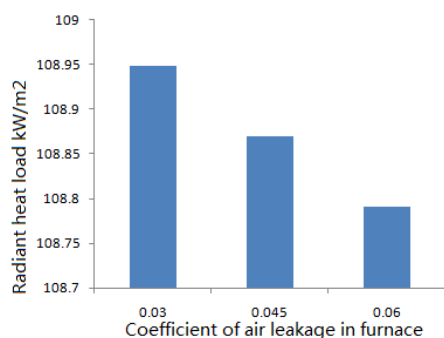


**Figure 3.** Temperature changes of low-temperature reheater.

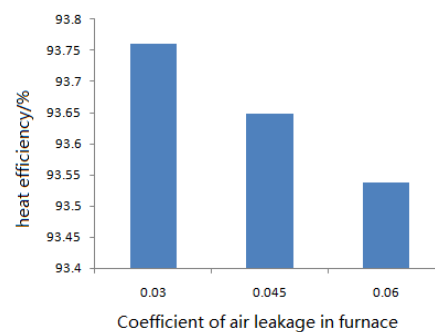
As seen from figures 2 and 3, the steam temperature in both upstream and downstream heat exchanger units is increased. The steam temperature in the upstream heat exchanger outlet is higher than in the downstream heat exchanger. That is, the upstream heat exchanger is more sensitive to leakage of the furnace.

The average radiation heat load of the furnace decreases with the leakage of air increase, the radiation heat absorption of water wall decreases, from the law of conservation of energy, the enthalpy of the flue gas at the outlet of the furnace can be increased, so the flue gas temperature increases.

When the leakage coefficient of the furnace is changed from 0.03 to 0.06, the radiant heat load of the furnace varies from 108.9478629 kW/m<sup>2</sup> to 108.7899275 kW/m<sup>2</sup>. The changing trend is shown in figure 4. From figure 5, it can be seen that the thermal efficiency of the boiler decreases with the leakage coefficient.



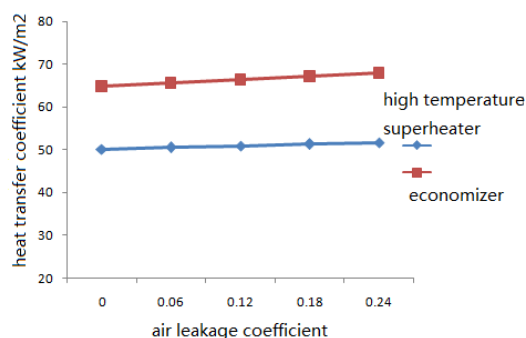
**Figure 4.** Radiant heat load change in the furnace.



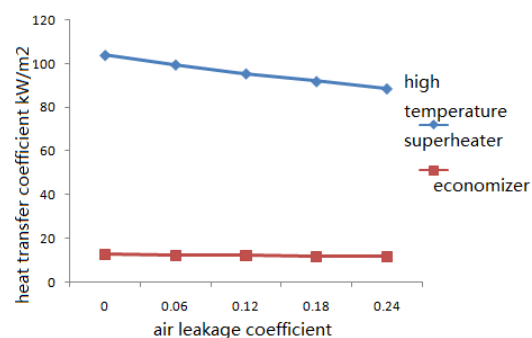
**Figure 5.** Heat efficiency change of boiler.

#### 4.2 The influence of flue air leakage on the system

The influence of the flue gas pipe on the radiative heat transfer coefficient of flue gas is relatively clear, the radiation heat transfer coefficient of flue gas is mainly affected by the flue gas temperature. The change of convection heat transfer coefficient and of radiation heat transfer coefficient can be seen in figures 6 and 7.



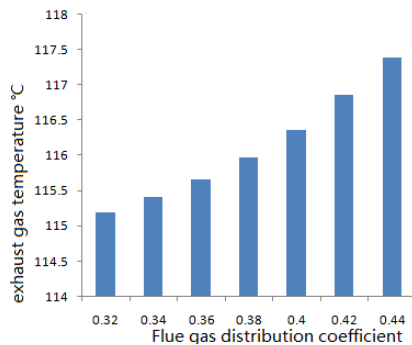
**Figure 6.** Change of convection heat transfer coefficient.



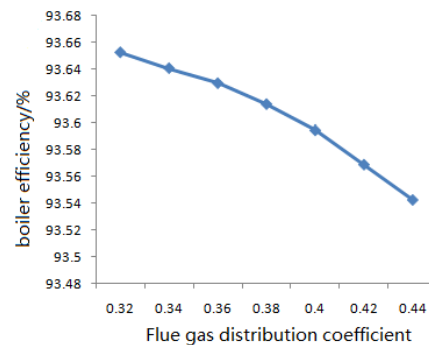
**Figure 7.** Change of radiation heat transfer coefficient.

#### 4.3 Influence of flue gas distribution coefficient in tail flue gas pipe on system

With an increase in flue gas distribution coefficient, the change of smoke temperature in the front smoke pipe is bigger and the smoke flow through the front flue increases. These two aspects cause the boiler exhaust gas temperature to rise and boiler efficiency to decrease, as shown in figures 8 and 9.



**Figure 8.** Change of exhaust gas temperature.



**Figure 9.** Change of boiler efficiency.

## 5. Conclusions

In this work, we simulate a thermodynamic model under BMCR condition, calculating the influence of furnace air leakage, leakage of smoke and flue gas distribution coefficient on the thermodynamic system. BMCR is boiler maximum continuous rating, maximum output in case of the steam parameter and furnace safety. Calculation results show that:

- When the air leakage in the furnace is changed from 0.03 to 0.06, the radiant heat load of the furnace varies from 108.9478629 kW/m<sup>2</sup> to 108.7899275 kW/m<sup>2</sup>. For a long time operation and a large area of heat exchange boiler, the heat loss will be very large, so a reasonable choice of air leakage coefficient has a great significance.
- The proportion of bituminous coal mixed from 32% to 44%, boiler efficiency decreased from 93.65 to 93.54. However, the flue gas temperature has risen 2.25°C, which makes the flue gas discharged into a higher atmosphere and partial pollution is reduced, so a reasonable choice of fuel mixture ratio has a great significance.

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