The research on the influence of carbon content in coal slag on heat loss from solid incomplete combustion

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Abstract. The influence of carbon content in coal slag on heat loss from solid incomplete combustion was analyzed by thermal balance calculation of the boiler. The results showed that the heat loss from solid incomplete combustion increased with the increase of carbon content in slag when other operating parameters were constant. The quality of coal, especially the calorific value had an important influence on the carbon content of the slag. The heat loss from solid incomplete combustion decreased with the increase of calorific value. As a result, in order to reduce the heat loss from solid incomplete combustion, the type of coal used should be consistent with the type of coal designed as much as possible.

1. Introduction
Industrial boiler is an important thermal power equipment, mainly used in the field of factory power, building heating and so on[1]. At present the efficiency of coal-fired industrial boilers in China is low generally. The potential for energy saving is great in boilers. The design efficiency of boiler is generally between 72% and 80%[2]. Due to various reasons, in China the average operating efficiency of industrial boiler is about 65%. Compared with developed countries, the average operating efficiency of coal boiler is commonly 10~15% below the value of efficiency[3].

The main reasons for the low efficiency of coal-fired industrial boilers are as follows. The average boiler load is less than 65%. The automatic control level is not advanced generally. The type of coal used is not consistent with the type of coal designed. The experience of boiler operators is lacked. The management level of energy saving is low, and so on[4]. The thermal efficiency of boiler depends on the various heat losses. The heat loss from solid incomplete combustion accounts for a large proportion of the factors affecting the thermal efficiency of the boiler[5]. Therefore, it is very important to analyze the factors of the heat loss from solid incomplete combustion in order to improve the thermal efficiency of boiler.

2. Heat loss of the boiler
The heat input to the boiler is equal to the sum of the effective utilization heat and heat losses of the boiler. Most of heat absorbed by the boiler is used to produce steam, which is the effective heat. The rest is the heat loss of the boiler[6]. The thermal balance equation is expressed as follow

\[ q_1 + q_2 + q_3 + q_4 + q_5 + q_6 = 100\% \] (1)

where \( q_1 \) is the percentage of effective utilization heat in boiler. \( q_2 \) is the heat loss from exhaust gas. \( q_3 \) is the heat loss from gas incomplete combustion. \( q_4 \) is the heat loss from solid incomplete combustion. \( q_5 \) is the surface heat loss. \( q_6 \) is the heat loss from coal slag and ash.
\( q_2 \) is the percentage of the heat that is taken away by exhaust gas in total input heat. It is calculated by the formula

\[
q_2 = \frac{K_{q4}}{Q_f} (h_{py} - h_{lk}) \times 100
\]  \hspace{1cm} (2)

where \( K_{q4} \) is correction factor. \( Q_f \) is the total heat into the boiler. \( h_{py} \) is the enthalpy of exhaust gas. \( h_{lk} \) is the enthalpy of air into the furnace.

The heat loss from gas incomplete combustion exists because the heat of combustible gas composition is not released completely. It is obtained from

\[
q_3 = \frac{V_g}{Q_f} K_{q4} \times (126.36CO + 107.98H_2 + 358.18C_m^{H_n'}) \times 100
\]  \hspace{1cm} (3)

where \( V_g \) is the volume of dry flue gas. \( CO', H_2' \) and \( C_m^{H_n'} \) are \( CO, H_2, C_m^{H_n} \) in the component content of exhaust gas, respectively.

The heat loss from solid incomplete combustion exists because combustible component of coal slag and ash is not burned completely[7]. It is expressed by

\[
q_4 = (\alpha_{lz} \frac{C_{lz}}{100-C_{lz}} + \alpha_{lm} \frac{C_{lm}}{100-C_{lm}} + \alpha_{fh} \frac{C_{fh}}{100-C_{fh}}) \times \frac{328.664A_{ar}}{Q_f}
\]  \hspace{1cm} (4)

where \( \alpha_{lz}, \alpha_{lm} \) and \( \alpha_{fh} \) are the percentage of coal slag, coal leakage and fly ash in the total amount of coal ash, respectively. \( C_{lz}, C_{lm} \) and \( C_{fh} \) are the combustible content of coal slag, coal leakage and fly ash, respectively. \( A_{ar} \) is the ash content of the coal as received basis.

For running boiler, the thermal efficiency of the boiler could be obtained through thermal balance experiment. And then the heat loss of the boiler is determined. An effective way could be obtained to improve the operating conditions and the thermal efficiency of the boiler[8].

3. Factors of the heat loss from solid incomplete combustion

There are many factors affecting the heat loss from solid incomplete combustion. The quality of coal, combustion equipment, furnace type, combustion mode, boiler load, operating parameters, furnace temperature, mixing of fuel and air flow all have an effect on the heat loss.

The heat loss from solid incomplete combustion mainly includes coal slag heat loss, fly ash heat loss and coal leakage heat loss. At present there is no limit on the carbon content of coal slag and fly ash in the relevant standards. According to the previous energy efficiency test data, the proportion of ash content in coal slag to the total ash content of incoming coal was approximately 50%. The proportion of ash content in coal leakage to the total ash content of incoming coal was 40%. The proportion of ash content in fly ash to the total ash content of incoming coal was 10%[9]. The coal slag and the coal leakage accounted for more than 90% of the heat loss from solid incomplete combustion. With the development of boiler operation management, the coal leakage could be reduced gradually because of cleaning regularly. As a result, the main factor of the heat loss from solid incomplete combustion is the carbon content in slag.

3.1. The influence of carbon content in coal slag on heat loss from solid incomplete combustion

![Figure 1. The relation between carbon content in coal slag and heat loss from solid incomplete combustion](image-url)
Figure 1 showed the influence of carbon content in coal slag on heat loss from solid incomplete combustion. When other operating parameters were constant, the heat loss from solid incomplete combustion increased with the increase of carbon content in slag. The heat loss from solid incomplete combustion increased about 1.15% when the carbon content of slag increased 2%.

![Figure 2. The relation between carbon content in coal slag and the proportion of heat loss from solid incomplete combustion in total heat loss](image)

It can be seen from Figure 2 that the proportion of heat loss from solid incomplete combustion in the total heat loss also increased when the carbon content of slag increased. The proportion of heat loss from solid incomplete combustion in the total heat loss increased 2.03% when the carbon content of coal slag increased 2%.

![Figure 3. The relation between carbon content in coal slag and thermal efficiency](image)

The relationship between the thermal efficiency and the carbon content in coal slag was shown in Figure 3. When other operating parameters were constant, the thermal efficiency decreased with the increase of carbon content in slag. The thermal efficiency decreased 1.16% when the carbon content of slag increased 2%.

The high carbon content of the slag indicated that the combustion of the coal in the furnace was not complete. The main reasons for the high carbon content of the coal slag are as follows. The average load of the boiler is low. The automatic control level is not advanced. The type of coal used is not consistent with the type of coal designed. The experience of boiler operators is lacked. The management level of energy saving is low, and so on.

3.2. The influence of calorific value on heat loss from solid incomplete combustion

![Figure 4. The relation between calorific value and heat loss from solid incomplete combustion](image)
Figure 4 showed the influence of coal’s calorific value on heat loss from solid incomplete combustion. When other operating parameters were constant, the heat loss from solid incomplete combustion decreased with the increase of calorific value. The heat loss from solid incomplete combustion decreased 1.74% when the coal’s calorific value increased 2.09 MJ/kg.

![Figure 5](image1.png)

Figure 5. The relation between calorific value and the proportion of heat loss from solid incomplete combustion in the total heat loss.

It can be seen from Figure 5 that the proportion of heat loss from solid incomplete combustion in the total heat loss also decreased when the coal’s calorific value increased. The proportion of heat loss from solid incomplete combustion in the total heat loss decreased 3.64% when the coal’s calorific value increased 2.09 MJ/kg.

![Figure 6](image2.png)

Figure 6. The relation between calorific value and thermal efficiency.

The relationship between the thermal efficiency and the coal’s calorific value was shown in Figure 6. When other operating parameters were constant, the thermal efficiency increased with the increase of coal’s calorific value. The thermal efficiency increased 1.85% when the coal’s calorific value increased 2.09 MJ/kg.

The coal-fired industrial boilers in China are mainly in the form of layer combustion. The adaptability of the coal to layer combustion is poor. When the burning coal is changed, the combustion condition of the boiler will change. In general, the combustion condition of the boiler is worse when the burning coal is changed. The quality, operation and management of the boiler have an effect on the combustion condition of the boiler. The quality of coal, especially the calorific value has an important influence on the carbon content of the slag. Then the heat loss from solid incomplete combustion and the thermal efficiency of boiler will change greatly.

The type of coal used is inconsistent with the type of coal designed. The combustion of the coal in the furnace is not complete. Therefore, the carbon content of coal slag is high. Then the thermal efficiency of coal boilers in China is generally lower than the designed efficiency. As a result, in order to reduce the heat loss from solid incomplete combustion, the type of coal used should be consistent with the type of coal designed as much as possible.

4. Conclusions

In this paper the influence of carbon content in coal slag on heat loss from solid incomplete combustion was analyzed. The results showed that the heat loss from solid incomplete combustion increased with the increase of carbon content in slag when other operating parameters were constant.
The heat loss from solid incomplete combustion increased 1.15% and the thermal efficiency decreased 1.16% when the carbon content of slag increased 2%. The proportion of heat loss from solid incomplete combustion in the total heat loss also increased with the increase of carbon content in slag.

The quality of coal, especially the calorific value had an important influence on the carbon content of the slag. The heat loss from solid incomplete combustion decreased with the increase of calorific value. The heat loss from solid incomplete combustion decreased 1.74% and the thermal efficiency increased 1.85% when the coal’s calorific value increased 2.09 MJ/kg. The proportion of heat loss from solid incomplete combustion in total heat loss also decreased when the calorific value increased. The type of coal used is inconsistent with the type of coal designed. The combustion in the furnace is not complete. Therefore, the carbon content of coal slag is high.

According to the research, the main reason for the increase of the heat loss from solid incomplete combustion could be obtained. The type of coal used is inconsistent with the type of coal designed. As a result, the thermal efficiency of coal boilers in China is generally lower than the designed efficiency.

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