Improvement of Performance Calculation Methods for Pulverized Coal and Blast-furnace Gas Co-fired Boilers

Yalan Ye[1*], Hongming Wang[1], Xiang An[1], Wenhao Jiang[2]

[1] Jiangsu Maritime Institute, Nanjing, Jiangsu, 211170, China
[2] MCC Huatian Engineering & Technology Corporation, Nanjing, Jiangsu, 210000, China
[*] Corresponding author's e-mail: yyl_jessica@sina.com

Abstract. In power plants of steel mills, the performance of pulverized coal and blast-furnace gas co-fired boilers was tested according to GB/T10184-2015 "Performance test code of utility boiler". However, the calculation and analysis models in this code are mainly based on conventional fuels. Besides, the special properties of blast furnace gas were not taken into account. Therefore, the code GB/T10184-2015 is not suitable to be directly used for pulverized coal and blast furnace gas co-fired boilers. According to the differences between co-fired boilers and conventional boilers, the key points for calculating the performance of co-fired boilers were analyzed on the basis of GB/T10184-2015, and the corresponding improved methods were proposed, in view of fuel composition conversion, combustion calculation, coal feed rate, exhaust gas temperature value, and pollutant emission concentration conversion. The results can provide reference for the performance test of such boilers, with certain practical significance.

1. Introduction

With the development of combustion technology, pulverized coal and blast-furnace gas co-fired boilers have been successfully applied in many steel plants (especially in steel plants of China). In this way, many problems existing in the separate combustion of blast-furnace gas can be solved effectively. Therefore, pulverized coal and blast-furnace gas co-fired boilers have been rapidly promoted in various steel enterprises.

In recent years, many scholars have carried out relevant research on pulverized coal and blast-furnace gas co-fired boilers. However, the research scope is mainly focused on the combustion, heat transfer, and emission characteristics [1]-[8]. There are few studies on the performance calculation of pulverized coal and blast-furnace gas co-fired boilers. At present, the main basis for the performance of boilers in steel plant is based on the Chinese standard GB/T10184-2015 "Performance test code of utility boiler" [9], which provides a method for analyzing the performance of co-fired boilers. However, this method is not suitable for pulverized and blast-furnace gas co-fired boilers directly. First, blast-furnace gas has high nitrogen content, its combustion calculation method is different from the traditional simplified method. Second, in converting the composition, only the moisture in the form of gaseous water vapor is considered, but the blast-furnace gas may contain moisture in the form of liquid droplets, neglecting liquid moisture or regard it as water vapor will inevitably cause errors in calculation results. Third, there are several layouts for the tail heating surface of pulverized coal and blast-furnace gas co-fired boilers, so the exhaust gas temperature should also be selected according to the heating surface layout. Therefore, for the pulverized coal and blast-furnace gas co-fired boilers, its performance calculation cannot directly apply GB/T10184-2015.

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In addition, it is difficult to accurately measure the mass flow of pulverized coal entering the furnace, leading to the difficulty in the boiler combustion calculation, and the concentration of atmospheric pollutants should not be converted directly according to the current method.
Thus, starting from fuel composition conversion, combustion calculation, coal feed rate, exhaust gas temperature value, and pollutant emission concentration conversion, we analyzed the performance calculation points of the pulverized coal and blast-furnace gas co-fired boilers that are different from conventional boilers, based on GB/T10184-2015. And we proposed corresponding improvement methods, which can provide reference for the performance test of the co-fired boilers.

2. Problems exit in current performance calculation methods

2.1. Combustion calculation model

The fuel combustion calculation is the primary task for boiler performance calculation. It mainly include calculating the amount of air required for combustion, excess air coefficient, and combustion products (flue gas). Among them, excess air coefficient is the key solution object. Based on the actual combustion conditions in GB/T10184, a correctional excess air coefficient calculation formula is given as follows:

$$\alpha = \frac{21\ \varphi_{\mathrm{N_2.fg.d}}}{21\ \varphi_{\mathrm{N_2.fg.d}} - 79\ \varphi_{\mathrm{O_2.fg.d}}} \tag{1}$$

Where, α is the correctional excess air coefficient, $\varphi_{\mathrm{O_2.fg.d}}$ and $\varphi_{\mathrm{N_2.fg.d}}$ are respectively the volume fractions of O_2 and N_2 in dry fuel gas.
GB/T 10184 also states that after ignoring the presence of combustible gases such as residual CO in the flue gas, the excess air coefficient can be calculated according to the simplified formula (2):

$$\alpha = \frac{21}{21 - \varphi_{\mathrm{O_2.fg.d}}} \tag{2}$$

The formula (2) is commonly used in engineering to calculate the excess air coefficient.
It can be seen that, in the calculation formula provided by GB/T10184, both the simplified formula (2) and formula (1) do not consider the effect of fuel nitrogen content on the excess air coefficient. This simplification is suitable for most fuels boilers, but not suitable for boilers burning blast-furnace gas. Blast-furnace gas is rich in nitrogen, resulting in a high nitrogen content in the mixed fuel. If the formula (1) or (2) is used to solve the excess air coefficient of pulverized coal and blast-furnace gas co-fired boilers, it will inevitably bring about error.

2.2. Conversion of fuel composition

Before combustion calculation is performed in a co-fired boiler, the characteristics of the mixed fuel should be converted through mass flow of the two fuels. Mixed fuel properties are generally calculated according to equation (3):

$$y_i = w_{\mathrm{coal}} x_{\mathrm{coal},i} + w_{\mathrm{gas}} x_{\mathrm{gas},i} \tag{3}$$

Where, y_i is a certain characteristic data for the mixed fuel; $x_{\mathrm{coal},i}$、$x_{\mathrm{gas},i}$ are the corresponding characteristic data of coal and blast-furnace gas respectively; w_{coal}、w_{gas} are the ratio of coal consumption and blast furnace gas consumption in total fuel consumption respectively.
When performing the above calculations, since the characteristics of the blast-furnace gas and the coal differ in the expression, it is necessary to convert the parameters of the blast-furnace gas in advance. Taking the fuel composition as an example, the gas volume components of the blast-furnace gas should be converted into elemental components expressed by mass fraction before they can be synthesized with the elemental components of the coal. Similarly, the ash and moisture should also be converted. Regarding composition conversion, GB/T 10184 gives the following calculation model:

$$w_{\mathrm{C.g}} = \frac{0.54}{\rho_{\mathrm{g.st}}}\left(\varphi_{\mathrm{CO.g}} + \varphi_{\mathrm{CO_2.g}} + \sum m\varphi_{\mathrm{C}_m\mathrm{H}_n.\,\mathrm{g}}\right) \tag{4}$$

$$w_{\mathrm{H.g}} = \frac{0.045}{\rho_{\mathrm{g.st}}}\left(2\varphi_{\mathrm{H_2.g}} + 2\varphi_{\mathrm{H_2S.g}} + \sum n\varphi_{\mathrm{C}_m\mathrm{H}_n.\,\mathrm{g}}\right) \tag{5}$$

$$w_{\mathrm{O.g}} = \frac{0.715}{\rho_{\mathrm{g.st}}}\left(\varphi_{\mathrm{CO.g}} + 2\varphi_{\mathrm{CO_2.g}} + 2\varphi_{\mathrm{O_2.g}}\right) \tag{6}$$

$$w_{\mathrm{N.g}} = \frac{1.25}{\rho_{\mathrm{g.st}}}\varphi_{\;2\;\mathrm{I}} \tag{7}$$

$$w_{\mathrm{S.g}} = \frac{1.43}{\rho_{\mathrm{g.st}}}\varphi_{\;2\;\mathrm{H}} \tag{8}$$

$$w_{\mathrm{m.g}} = \frac{0.8}{\rho_{\mathrm{g.st}}}\varphi_{\mathrm{wv.g}} \tag{9}$$

$$w_{\mathrm{as.g}} = \frac{0.1}{\rho_{\mathrm{g.st}}}\rho_{\mathrm{as.g}} \tag{10}$$

Where, $w_{\mathrm{C.g}}$、$w_{\mathrm{H.g}}$、$w_{\mathrm{O.g}}$、$w_{\mathrm{N.g}}$、$w_{\mathrm{S.g}}$、$w_{\mathrm{m.g}}$、$w_{\mathrm{as.g}}$ are the mass fraction of the element carbon, hydrogen, oxygen, nitrogen, sulfur, steam, and ash in blast-furnace gas respectively; $\rho_{\mathrm{g.st}}$ is the density of blast-furnace gas under standard conditions, and is calculated as follow:

$$\begin{aligned}\rho_{\mathrm{g.st}} = {} & 0.0125\varphi_{\mathrm{CO.g}} + 0.0009\varphi_{\mathrm{H_2.g}} + 0.01\sum(0.54m + 0.045n)\varphi_{\mathrm{C}_m\mathrm{H}_n\mathrm{.g}} + 0.0152\varphi_{\mathrm{H_2S.g}} \\ & + 0.0196\varphi_{\mathrm{CO_2.g}} + 0.0125\varphi_{\mathrm{N_2.g}} + 0.0143\varphi_{\mathrm{O_2.g}} + 0.008\varphi_{\mathrm{wv.g}} + 0.001\rho_{\mathrm{as.g}}\end{aligned} \tag{11}$$

Where, φCO.g、φH$_2$.g、φC$_m$H$_n$.g、φH$_2$S.g、φCO$_2$.g、φN$_2$.g、φO$_2$.g、φwv.g are volume fraction (%) of CO, C_mH_n, H_2S, CO_2, N_2, O_2 and water vapor in blast-furnace gas respectively; $\rho_{\mathrm{as.g}}$ is the mass concentration of ash in blast-furnace gas.

It can be seen that the national standard GB/T10184 only considers the moisture in gaseous fuels in the form of gaseous water vapor. This can be applied to most gaseous fuels, but should not be applied directly to metallurgical blast-furnace gas. Because the blast-furnace gas may contain moisture in the form of mechanical water, which is related to the upstream blast-furnace gas dust removal process: If the wet dust removal process is used, the blast-furnace gas after dust removal treatment will contain not only saturated water vapor but also mechanical water in the form of liquid droplets; If a dry dust removal process is used, since the blast-furnace gas does not touch water in the dust removal process, the gas contains only a small amount of water vapor, so it will not carry mechanical water.

Obviously, for the blast-furnace gas after wet dust collection, the water content in the form of mechanical water should be taken into account in the composition conversion. Therefore, it is necessary to improve the relevant formula in GB/T10184.

2.3. Measurement of pulverized coal entering into the boiler furnace

For pulverized coal and blast-furnace gas co-fired boilers, the coal mass flow fed into the boiler furnace is the basic input parameter for solving the mixed fuel composition, and it is an indispensable basic data for calculating the performance of the co-fired boiler. However, until now, the accurate measurement for the mass flow of coal entering the furnace is still an unsolved technical problem, especially for the middle storage pulverizing system, the mass flow measured by the coal feeder cannot represent the pulverized coal mass flow fed into the furnace. The relevant technicians have not yet found a recognized reliable solution for this problem.

The measurement of the fed mass flow of pulverized coal will not affect the performance calculation for conventional coal-fired boilers, because the performance of the boiler fired single fuel is calculated based on the per-mass fuel. But for the pulverized coal and blast-furnace gas co-fired boilers, if the mass flow of pulverized coal cannot be accurately measured, it will directly affect the solution of the mixed fuel characteristics, and so will affect other subsequent calculations. Therefore, constructing a practical and reliable method to obtain the pulverized coal flow, must be solved to enable the performance calculation of the co-fired boiler can be carried out smoothly.

2.4. Selection of flue gas exhaust temperature

The temperature of the flue gas is an important parameter to characterize the operation economy for the boiler, and it can affect the heat loss of the flue gas and affect the boiler efficiency. GB/T10184 takes the air preheater as the last stage heating surface in the boiler tail, so the outlet flue gas temperature of the air preheater is used as the exhaust temperature. This is suitable for conventional boilers, but for pulverized coal and blast-furnace gas co-fired boilers, it may not be suitable. The co-fired boilers is different from the conventional boiler in the design for tail heating surface. Therefore, the temperature value of the exhaust gas must be differentiated according to the characteristics of the heating surface.

2.5. Conversion of air pollutants emission concentration

GB/T10184 provides the method for measuring the emission concentration of boiler air pollutants (including NO_x, SO_2 and so on). Taking SO_2 emission concentration as an example, GB/T10184 points out that the emission concentrations of SO_2 and O_2 in flue gas should be measured at the same time, and then the measured SO_2 concentration should be converted to the standard concentration with excess air coefficient as 1.4, according to GB13223. The conversion formula is as follows:

$$\rho_{SO_2.re} = \rho_{SO_2.m}\frac{\alpha}{1.4} \tag{12}$$

Where, $\rho_{SO_2.re}$ is the mass concentration of SO_2 converted to the excess air coefficient as 1.4, mg/m^3; $\rho_{SO_2.m}$ is the measured SO_2 mass concentration in the flue gas, mg/m^3.

According to the GB/T10184, we consulted GB13223 "Emission Standard of Air pollutants for Thermal Power Plants", in which the 2003 version (GB13223-2003[10]) stipulated that the emission concentration should be converted by the excess air coefficient α, and the coefficient of coal-fired boiler was given as α=1.4. The 2011 version (GB13223-2011[11]) replaced it with the oxygen content and specifies the reference oxygen content for various types of thermal energy conversion facilities, as showed in Table1.

Table1. Reference oxygen content

No	Thermal energy conversion facility type	Reference oxygen content /%
1	Coal-fired boiler	6
2	Oil or gas boiler	3
3	Gas turbine unit	15

It can be seen that, according to GB13223-2011, the conversion factor 1.4 in equation (12) corresponds to the reference oxygen content of 6%. However, for the pulverized coal and blast-furnace gas co-fired boiler, this conversion method has the following two problems:

1) Due to the high nitrogen content in the fuel, the excess air coefficient should not be calculated through the simplified formula shown in equation (2), but should be calculated through the exact formula considering nitrogen content in the fuel. The results from the two formulas are different, so simplifying the excess air coefficient value as 1.4 will inevitably cause large errors.

2) Pulverized coal and blast-furnace gas co-fired boilers are divided into two types: one is based on the structure of pulverized coal boiler, and the other is based on structure of gas boiler. Since current standards only stipulate the reference oxygen content in a single fuel boiler, and no special provisions have been made for the co-fired boiler. Thus, the pulverized coal and blast-furnace gas co-fired boilers can only be classified as coal-fired boilers or gas-fired boilers. For the first type co-fired boiler, the reference oxygen content should be selected as pulverized coal boiler. And for the second co-fired boiler, the reference oxygen content should be selected as gas boiler. Obviously, with different oxygen content, the corresponding conversion coefficient is also different.

Therefore, when measuring the concentration of pollutants discharged from pulverized coal and blast-furnace gas co-fired boilers, the method in GB/T10184 should not be directly applied. Otherwise, the results may be seriously distorted.

3. Improvements of the performance calculation methods

3.1. Improvement of combustion calculation model

For pulverized coal and blast-furnace gas co-fired boilers, the excess air coefficient should be solved according to the complete calculation formula, as follows:

$$\alpha=\frac{21}{21-79\dfrac{\varphi_{O_2.fg.d}}{\varphi_{N_2.fg.d}-\dfrac{0.8w_{N.ar}}{V_{fg.d}}}} \tag{13}$$

Where, w_{N}.ar is the mass fraction of nitrogen elemental in the mixed fuel; $V_{fg.d}$ is the volume of dry flue gas generated from the mixed fuel combustion, m^3/kg, and the formula is as follows:

$$V_{fg.d}=V_{fg.d.th}+(\alpha-1)V_{a.d.th} \tag{14}$$

Where, $V_{fg.d.th}$ is the theoretical dry flue gas volume generated by per kilogram of mixed fuel combustion; $V_{a.d.th}$ is the theoretical dry air volume required by per kilogram of mixed fuel combustion.

Formula (13) can be derived from the definition of the excess air coefficient and the air component. Due to limited space, the derivation process is omitted here. By comparing equations (1) and (2) with the modified formula (13), it can be found that formula (1) is a simplified formula that ignores the effect of containing N in the fuel, and formula (2) is based on formula (1) and is simplified with the further assumption that N_2 in dry flue gas is close to 79%. Obviously, the above simplified conditions are not applicable to the burning blast-furnace gas with rich N element.

3.2. Improvement of fuel composition conversion model

For the blast-furnace gas carrying mechanical water, the mechanical water should be taken into account, and the water mass should be calculated according to formula (15):

$$w_{m.g}=\frac{0.8}{\rho_{g.st}}\varphi_{wv.g}+d_{jx} \tag{15}$$

Where, $w_{m.g}$ is the mass fraction of water in blast-furnace gas, %; d_{jx} is the mechanical water mass in unit volume of blast-furnace gas, kg/m^3.

Correspondingly, the calculation formula for the blast-furnace gas density shown in equation (11) also needs to be adjusted. The improved formula is as follows:

$$\begin{aligned}\rho_{g.st}&=0.0125\varphi_{CO.g}+0.0009\varphi_{H_2.g}+0.01\sum(0.54m+0.045n)\varphi_{C_mH_n.g}+0.0152\varphi_{H_2S.g}\\&+0.0196\varphi_{CO_2.g}+0.0125\varphi_{N_2.g}+0.0143\varphi_{O_2.g}+0.008\varphi_{wv.g}w_{m.g}+0.001\rho_{as.g}+d_{jx}\end{aligned} \tag{16}$$

Obviously, using formula (15) instead of formula (9) to characterize the moisture content in blast-furnace gas appears more reasonable. The formula (15) has better applicability and it can be used not only for wet gas with gaseous water vapor, but also for wet gas that contains liquid mechanical water. For wet gas carrying mechanical water, φwv.g in equation (15) is the volume fraction of saturated steam in the wet gas, which can be obtained from the gas temperature.

3.3. Solving model of coal mass flow injected into the boiler furnace

In order to solve the problem of measuring the mass flow of pulverized coal injected into the boiler furnace, this paper proposes a soft measurement method based on the content of triatomic gas in the flue gas. The specific steps are as follows:

1) Assume that the mass flow of pulverized coal entering the furnace is B_c;

2) Convert the coal composition and the blast-furnace gas composition to the mixed fuel composition data by formulas (3) to (11), based on the presumed coal mass flow B_c and the measured gas volume B_g. The result includes mass fraction of elemental carbon, hydrogen, oxygen, nitrogen, sulfur, and ash.

3) Calculate the mass fraction of carbon actually burned in boiler furnace:

$$w_{C.b}=w_{C.ar}-\frac{w_{as.ar}}{100}\left(\frac{w_s w_{c.s}}{100-w_{c.s}}+\frac{w_{pd}w_{c.pd}}{100-w_{c.pd}}+\frac{w_{as}w_{c.as}}{100-w_{c.as}}\right) \tag{17}$$

Where, $w_{C.b}$ is the mass fraction of carbon actually burned in boiler furnace, %; $w_{C.ar}$, $w_{as.ar}$ are the mass fraction of carbon and ash in the mixed fuel, %; w_s, w_{pd}, w_{as} are respectively the percentage of slag, sedimentation ash and fly ash in the total ash content, %; $w_{c.s}$, $w_{c.pd}$, $w_{c.as}$ are respectively the mass fraction of slag in slag, settlement ash and fly ash, %;

4) Calculate the fuel characteristic coefficient:

$$\beta = 2.35\frac{w_{H.ar} - 0.126w_{O.ar} + 0.038w_{N.ar}}{w_{c.b} + 0.375w_{S.ar}} \tag{18}$$

Where, β is the fuel characteristic coefficient; $w_{H.ar}$, $w_{O.ar}$, $w_{N.ar}$, $w_{S.ar}$ are respectively the mass fraction of elemental hydrogen, oxygen, nitrogen, and sulfur in the mixed fuel;

5) Solve the theoretical content of triatomic gas RO_2 in dry flue gas based on the oxygen content of the flue gas and the fuel characteristic coefficient:

$$\varphi_{RO_2.fg.th.d} = \frac{21 - \varphi_{O_2.fg.d}}{1+\beta} \tag{19}$$

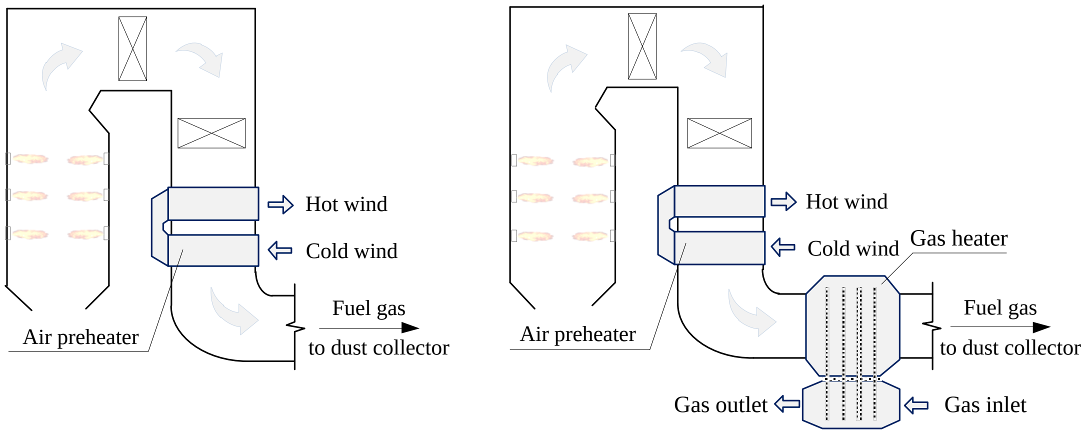
Where, $\varphi_{RO_2.fg.th.d}$ is the theoretical volume fraction of triatomic gas RO_2 in dry fuel gas, %;

6) Compare the theoretical volume fraction of triatomic gas RO_2 in the dry flue gas with the measured value, and determine whether the difference between the two is within the set error range. If it is not satisfied, then re-assumed the coal amount B_c, and perform step 2) ~ step 6) again;

7) Output B_c as the final pulverized coal mass flow.

3.4. Improvement of the exhaust temperature value selection

The exhaust fuel gas temperature of the pulverized coal and blast-furnace gas co-fired boilers shall be differentiated, according to setting characteristics of the boiler tail heating surface. Figure 1 shows the most common two heating surface layouts:



a) Conventional pulverized coal and blast-furnace gas co-fired boilers

b) Pulverized coal and blast-furnace gas co-fired boiler with gas heater

Figure1. The tail heating surface layout of the pulverized coal and blast-furnace gas co-fired boiler

1) Figure1-a shows the conventional pulverized coal and blast-furnace gas co-fired boiler whose tail heating surface is set in the same way as the conventional boiler. The last stage of the boiler tail heating surface is the air preheater. For this type of boiler, the outlet gas temperature of the air preheater should be taken as the boiler exhaust temperature.

2) Figure1-b shows the new type of pulverized coal and blast-furnace gas co-fired boiler that has been used in some steel plants in recent years. A gas heater has been added in the boiler tail, in order to recover the residual heat of the flue gas and improve the combustion of blast furnace gas. For such boilers, the outlet gas temperature of the gas heater should be taken as the boiler exhaust temperature.

3.5. Improvement of the air pollutants emission concentration conversion method

The analysis showed that the origin of the air pollutants emission concentration through excess air coefficient is as follows: For conventional fuel boilers (especially coal-fired boilers), theoretical dry air volume $V_{a.d.th}$ and theoretical dry flue gas volume $V_{fg.d.th}$ are very close, so the formula (14) can be simplified to $V_{fg.d} = \alpha V_{a.d.th}$, and then the conversion method based on the excess air coefficient was obtained. However, for the pulverized coal and blast-furnace gas co-fired boiler, the theoretical dry air volume and the theoretical dry flue gas volume differ greatly, and the greater the mixing ratio of blast-furnace gas, the greater the difference between the theoretical dry air volume and the theoretical dry flue gas volume. Therefore, the dry fuel gas volume of the co-fired boiler cannot be simplified, and the concentration of air pollutants emissions should not be converted according to the excess air coefficient. Effectively, the emission concentration should be converted by the oxygen content in the flue gas as follows:

$$\rho_{re} = \frac{21 - \varphi_{O_2.fg.d.m}}{21 - \varphi_{O_2.fg.d.re}} \rho_m \tag{20}$$

Where, ρ_{re}, ρ_m are the emission concentration of air pollutants converted to the reference oxygen content and the measured emission concentration, respectively, mg/m^3; $\varphi_{O_2.fg.d.re}$, $\varphi_{O_2.fg.d.m}$ are the reference oxygen content and the measured oxygen content, respectively.

Formula (20) can be derived through the calculated relationship between the concentration of gaseous pollutants and the dry flue gas volume. It is applicable to various combustion conditions and is currently used by most environmental protection standards.

For the pulverized coal and blast-furnace gas co-fired boilers, it can be seen from the analysis in Part 1.5 that the reference oxygen content should be distinguished by the boiler type. In addition, in the standards for pollutant emissions in China, according to the size of boiler capacity, the boiler with an output above 65t/h should comply with the standard GB13223-2011 "Emission Standard of Air pollutants for Thermal Power Plants", and the boiler with output of 65t/h and below 65t/h should comply with the standard GB13271-2014 "Emission Standard of Air pollutants for Boilers" [12], while the requirements for reference oxygen content in GB13223 and GB13271 also have some differences. In summary, the selection of reference oxygen content for the pulverized coal and blast-furnace gas co-fired boilers should be combined with the furnace type and the boiler capacity, as shown in Table 2.

Table2. Reference oxygen content of pulverized coal and blast-furnace gas co-fired boilers

Boiler type	Boiler capacity / t h^{-1}	Reference oxygen content / %
Pulverized coal boiler (co-fired gas)	>65	6
	≤65	9
Gas boiler (co-fired pulverized coal)	>65	3
	≤65	3.5

4. Conclusion

In engineering, the performance of pulverized coal and blast-furnace gas co-fired boilers are tested mainly according to Chinese GB/T10184-2015 "Performance test code for utility boiler". However, the calculation model in this regulation is mainly based on conventional fuels such as coal, oil or natural gas, it does not take the special properties of blast-furnace gas and the characteristics of the boiler tail heating surface into account. Thus, GB/T10184-2015 cannot be directly used in pulverized coal and blast-furnace gas co-fired boilers.

In this paper, several characteristics of pulverized coal and blast-furnace gas co-fired boilers different from conventional boilers were analyzed, and the problems of GB/T10184 has been pointed out and the corresponding improved methods were proposed. Eventually, the following conclusions were obtained:

1) Because of the high nitrogen content in blast-furnace gas, the combustion calculation (especially the solving of excess air coefficient) for the pulverized coal and blast-furnace gas co-fired boiler should not adopt the conventional simplified formula, but should adopt the complete calculation method considering the fuel composition.

2) When solving the characteristics of the mixed fuel, the blast-furnace gas components should be generally converted into elemental components expressed in terms of the received mass fraction, and then combine with the coal components. In moisture conversion, since the blast-furnace gas may contain moisture in the form of mechanical water, the conversion model should also take it into account, in order to avoid the fact that traditional method ignoring mechanical water will cause the calculation error.

3) The mass flow of pulverized coal entering the boiler furnace is essential data for calculating the performance of the pulverized coal and blast-furnace gas co-fired boiler. However, it is difficult to accurately measure the mass flow of pulverized coal, especially for the boiler with intermediate storage pulverizing system. It will undoubtedly hinder the smooth implementation of the related calculations. For this reason, this paper proposed a soft measurement method based on the content of triatomic gas in the flue gas, which skillfully solves the problem.

4) There are two layouts for the tail heating surface of pulverized coal and blast-furnace gas co-fired boiler. One is to adopt the air preheater as the final heating surface. For this type of boilers, the outlet flue gas temperature of the air preheater should be taken as the boiler exhaust temperature. The other is to adopt the gas heater as the last heating surface. For this type of boilers, the outlet gas temperature of the gas heater should be taken as the boiler exhaust temperature.

5) The pollutants emission concentration from pulverized coal and blast-furnace gas co-fired boilers shall not be converted through the excess air coefficient, it shall be converted through the oxygen content in flue gas, and the reference oxygen content shall be selected according to the boiler type and output capacity.

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Acknowledgements

This work was supported by the Natural Science Foundation of the Jiangsu Higher Education Institutions of China (Grant No. 17KJD470001) and sponsored by Qing Lan Project of the Jiangsu Higher Educaion Institutions of China.