IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

A new method for boiler combustion calculation

To cite this article: Xuechao Zhang *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **199** 032083

A new method for boiler combustion calculation

Xuechao Zhang[1], Yalan Ye[2*], Hongming Wang[2], Xiang An[2]

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

Abstract. Fuel combustion calculation is an important basic work of boiler performance test and analysis. During the process of combustion calculation, solving excess air ratio and actual volume of dry flue gas are key objectives. Current method is to firstly calculate excess air ratio, then calculate actual volume of dry flue gas. And in order to solve excess air ratio, almost all fue gas composition need to be measured, which will not only increase the workload of measurement, but also reduce the accuracy of calculation results. To this end, a new combusion calculating method is proposed in this paper which solves actual dry flue gas ratio through oxygen content in flue gas, thus actual volume of dry flue gas is calculated. Finally, the excess air ratio is obtained through acutal volume of dry flue gas. By the new method, the flue gas composition measure items can be reduced to only oxygen content, but it will not reduce the precision of combustion calculation.

1. Introduction
Combustion calculation is an important basic task in boiler design process, it is also a necessary work for boiler performance test and calculation analysis. The main objects of combustion calculation include excess air ratio, air volume needed by combustion, flue gas volume generated from combustion etc., in which the excess air ratio and actual volume of dry flue gas are the key calculating items [1, 2, 3].

For a long time, when boiler combustion calculation is conducted, the excess air ratio is firstly calculated based on flue gas composition, and then the actual volume of dry fuel gas is solved based on excess air ratio [4, 5]. This method is widely used in engineering, but in practical application, almost all flue gas composition need to be measured, which not only makes requests to equipment, but also causes the increase of combustion calculation error, due to the error of flue gas composition measurement.

Starting from the basic calculation model of fuel combustion, a new combustion calculation is obtained by derivation, which can provide a new thought for boiler performance test. Comparing with the current method, the new method can greatly reduce measurement items of flue gas, and can simplify the combustion calculating process as well.

2. Current combustion calculation method

2.1. Calculation model
The current calculation models are as follows [4]:

- Calculation model of excess air ratio:

$$\alpha = \frac{21\varphi'(\mathrm{N_2})}{21\varphi'(\mathrm{N_2}) - 79\varphi'(\mathrm{O_2})} \quad (1)$$

Where α is the excess air ratio; $\varphi'(N_2)$, $\varphi'(O_2)$ is the volume fraction % of N_2 and O_2 in dry flue gas respectively.

● Calculation model of dry flue gas volume:

$$V_{\mathrm{fg.d}} = V_{\mathrm{fg.d.th}} + (\alpha - 1)V_{\mathrm{a.d.th}} \quad (2)$$

Where $V_{\mathrm{fg.d}}$ is the actual volume of dry flue gas generated from the unit fuel combustion, the unit is m^3/kg (solid or liquid fuels) or m^3/m^3 (gas fuels); $V_{\mathrm{a.d.th}}$ and $V_{\mathrm{fg.d.th}}$ is the theoretical volume of dry flue gas generated from combustion of unit fuel and the theoretical volume of dry air needed by unit fuel combustion respectively, the unit is m^3/kg (solid or liquid fuels) or m^3/m^3 (gas fuels), which can be obtained by fuel composition.

● Calculation models for theoretical volume of dry air and theoretical volume of dry flue gas

For liquid fuels, $V_{\mathrm{a.d.th}}$ and $V_{\mathrm{fg.d.th}}$ can be solved based on formula (3) and formula (4) respectively:

$$V_{\mathrm{a.d.th}} = 0.0888w(\mathrm{C_{ar}}) + 0.0333w(\mathrm{S_{ar}}) + 0.2647w(\mathrm{H_{ar}}) - 0.0334w(\mathrm{O_{ar}}) \quad (3)$$

$$V_{\mathrm{fg.d.th}} = 1.8658\frac{w(\mathrm{C_{ar}})}{100} + 0.6989\frac{w(\mathrm{S_{ar}})}{100} + 0.79V_{\mathrm{a.d.th}} + 0.8\frac{w(\mathrm{N_{ar}})}{100} \quad (4)$$

Where $w(C_{ar})$, $w(H_{ar})$, $w(O_{ar})$, $w(N_{ar})$, and $w(S_{ar})$ is the mass fraction % of the elements C, H, O, N, and S in the fuels respectively.

For solid fuels, the calculation formula is similar to liquid fuels, the difference is that $w(C_{ar})$ in formula (3) and formula (4) is the actually burned carbon mass fraction.

For gas fuels, $V_{\mathrm{a.d.th}}$ and $V_{\mathrm{fg.d.th}}$ are solved through formula (5) and formula (6) respectively as follow:

$$V_{\mathrm{a.d.th}} = \frac{1}{21}\left[0.5\varphi(\mathrm{H_2}) + 0.5\varphi(\mathrm{CO}) + \sum(m + 0.25n)\varphi(\mathrm{C}_m\mathrm{H}_n) + 1.5\varphi(\mathrm{H_2S}) - \varphi(\mathrm{O_2})\right] \quad (5)$$

$$V_{\mathrm{fg.d.th}} = \frac{1}{100}\left[\varphi(\mathrm{CO_2}) + \varphi(\mathrm{CO}) + \sum m\varphi(\mathrm{C}_m\mathrm{H}_n) + \varphi(\mathrm{H_2S})\right] + 0.79V_{\mathrm{gk}}^{0} + \frac{1}{100}\varphi(\mathrm{N_2}) \quad (6)$$

Where $\varphi(H_2)$, $\varphi(CO)$, $\varphi(C_mH_n)$, $\varphi(H_2S)$, $\varphi(O_2)$, $\varphi(CO_2)$ and $\varphi(N_2)$ is the volume fraction % of H_2, CO, C_mH_n, H_2S, O_2, CO_2 and N_2 in the gas fuels respectively.

2.2. Application characteristics

We know from the above calculation models that in current calculation method, the oxygen content and nitrogen content of flue gas need to be input. When testing boiler performance, it is easy to measure oxygen content in flue gas, but it's hard to directly measure nitrogen content, which is generally obtained through indirect means. In this method, the volume contents of all other gases are measured, and then nitrogen content is inversely calculated by the measured compositions. Thus, if boiler performance test is conducted through the current method, all the other flue gas compositions need to be measured except N_2.

3. New combustion calculation

3.1. New model of combustion calculation

In this paper, a new combustion calculation model is proposed. The specific formulas are as follows:

● Calculation model of actual dry flue gas volume:

$$V_{\mathrm{fg.d}} = kV_{\mathrm{fg.d.th}} \quad (7)$$

Where k is the actual dry flue gas ratio that is calculated as follow:

$$k = \frac{21}{21 - \varphi'(\mathrm{O_2})} \quad (8)$$

● Calculation model of excess air ratio:

$$\alpha = \frac{V_{\mathrm{fg.d}} - V_{\mathrm{fg.d.th}}}{V_{\mathrm{a.d.th}}} + 1 \quad (9)$$

3.2. Derivation of calculation model

● Derivation process of calculation model for actual volume of dry flue gas

The excess air volume $\Delta V_{\mathrm{a.d}}$ corresponding to unit fuel combustion is generally solved through excess air ratio and theoretical volume of dry flue gas, as shown in formula (10):

$$\Delta V_{\mathrm{a.d}} = (\alpha - 1) V_{\mathrm{a.d.th}} \quad (10)$$

In addition, $\Delta V_{\mathrm{a.d}}$ can also be calculated according to oxygen content in flue gas and actual volume of dry flue gas, as shown in formula (11):

$$\Delta V_{\mathrm{a.d}} = \frac{1}{21} \varphi'(\mathrm{O_2}) V_{\mathrm{fg.d}} \quad (11)$$

We can get formula (12) by combing formula (10) and formula (11):

$$(\alpha - 1) V_{\mathrm{a.d.th}} = \frac{1}{21} \varphi'(\mathrm{O_2}) V_{\mathrm{fg.d}} \quad (12)$$

Substitute formula (12) to formula (2), we can obtained as follow:

$$\begin{aligned} V_{\mathrm{fg.d}} &= V_{\mathrm{fg.d.th}} + (\alpha - 1) V_{\mathrm{a.d.th}} \\ &= V_{\mathrm{fg.d.th}} + \frac{1}{21} \varphi'(\mathrm{O_2}) V_{\mathrm{fg.d}} \end{aligned} \quad (13)$$

Formula (14) can be obtained by reorganizing formula (13):

$$\left[1 - \frac{1}{21} \varphi'(\mathrm{O_2})\right] V_{\mathrm{fg.d}} = V_{\mathrm{fg.d.th}} \quad (14)$$

So the calculation formula for $V_{\mathrm{fg.d}}$ can be obtained as follow:

$$V_{\mathrm{fg.d}} = \frac{21}{21 - \varphi'(\mathrm{O_2})} V_{\mathrm{fg.d.th}} \quad (15)$$

● Derivation process of calculation model of excess air ratio

It's relatively easy to derivate the new calculation model of excess air ratio, which can be obtained by directly deflecting formula (2).

4. Comparison with the current method

4.1. Characteristics comparison

● Calculation thought comparison

The calculation thought of the current method is to firstly calculate excess air ratio, then solve the actual volume of dry flue gas. On the contrary, the new method is to firstly solve the actual volume of dry flue gas, then calculate excess air ratio.

● Input parameter comparison

The current method need to input O_2 and N_2 contents of the flue gas, in which N_2 content needs to be obtained from other compositions. So the current method needs to test all flue gas compositions except N_2. But in contrast, the new method only needs to test O_2 content in flue gas.

4.2. Calculation results comparison

Taking a coal-fired boiler and an oil-fired boiler as example, the test data is used for combustion calculation, including fuel compositions and fuel gas compositions. The calculation is based on current method and the proposed new method in this paper respectively, and the results are shown in Table 1.

Table1. The results of combustion calculation for typical fuel boiler

Item		Coal-fired boiler	Oil-fired boiler
Fuel compositions	$w(C_{ar})$ /%	51.42	83.97
	$w(H_{ar})$ /%	3.01	14.20
	$w(O_{ar})$ /%	7.22	0.76
	$w(N_{ar})$ /%	1.45	0.44
	$w(S_{ar})$ /%	0.74	0.55
Flue gas compositions	$\varphi'(O_2)$ /%	5.07	3.05
	$\varphi'(RO_2)$ /%	14.46	12.70
	$\varphi'(N_2)$ /%	80.47	84.25
Calculation results of α	Through current method	1.311	1.158
	Through new method	1.312	1.158
Calculation results of $V_{fg.d}$	Through current method	6.652	12.230
	Through new method	6.658	12.234

Note: RO_2 is the triatomic gas, including CO_2 and SO_2.

From Table 1 we can see that excess air ratio and actual volumes of dry flue gas calculated through the current method and new method are basically identical, with small difference. As both methods are obtained from theoretical derivation, their results should be equal. We think the results difference between the two methods may come from the test error of the flue gas compositions.

5. Conclusion

In the traditional combustion calculation process, the excess air ratio is firstly calculated, and then the actual volume of dry flue gas is solved. Meanwhile almost all flue gas compositions need to be measured for solving the excess air ratio.

A new method for combustion calculation is proposed. In this method, the actual volume of dry flue gas is solved at first, based on actual ratio of dry flue gas that is obtained by oxygen content in flue gas. Then, the excess air ratio is calculated.

By the new method, combustion calculating process is simplified, and the measurement items of the flue gas compositions are reduced. The research results in this paper can provide a reference for the test and analysis of boiler performance.

Acknowledgements

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

References

[1] Zhenning Zhao, Qingfeng Zhang, Zhenzhou Zhao. Principle, method and calculation of performance test for utility boiler. China Electric Power Press, Beijing, 2010, 38~46.
[2] Qiangtai Zhou, Keyi Zhou, Wei Len, Hui Zhong. Boiler principle. 2nd edition. China Electric Power Press, Beijing, 2009, 26~31.
[3] Tongmo Xu, Zonghu Lin. Practical boiler manual. Chemical Industry Press, Beijing, 2009, 59~65.
[4] National energy bureau of china. Technical code for design and calculation of combustion system in fossil-fired power plan. China Electric Power Press, Beijing, 2011, 42~48.
[5] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China. GB/T 10184-2015 Performance test code for utility boiler. China Standards Press, Beijing, 2016, 32~37.