Discussion on Relevant Issues of Thermal performance test code for industrial boilers

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Abstract: In the study and application of GB/T 10180-2017 "Thermal performance test code for industrial boilers", the author found some unreasonable or error-prone areas in the rules. In this paper, the value of boiler thermal efficiency, the test method of condensing boiler, the correction method of boiler thermal efficiency and the calculation of desulfurization thermal efficiency are discussed, and personal suggestions are put forward.

1. Preface
GB/T 10180-2017 "Thermal performance test code for industrial boilers" (here in after referred to as GB/T 10180-2017) was issued in 2017 and implemented on February 1, 2018. The standard specifies the terms and definitions, symbols and units, general principles, test preparation, test requirements, measurement items and test instruments, test methods, calculation of boiler thermal efficiency and test reports in the thermal performance test of industrial boilers [1]. In the process of learning and using the regulations, some unreasonable or error-prone places in the regulations have been found. This paper discusses these problems.

2. Discussion on Relevant Issues
2.1Boiler thermal efficiency adopts the average value of direct and indirect balance
Direct balance measurement is a method of directly measuring input heat and output heat to determine boiler thermal efficiency, also known as direct measurement or input-output method. According to the definition of direct balance measurement method, we can conclude that the advantages of direct balance measurement method are: direct measurement to determine the main parameters of efficiency (input and output); Less measurement is required; There is no need to estimate the loss that cannot be measured. The disadvantages of direct balance measurement method are: accurate measurement of fuel quantity, fuel calorific value, steam flow rate and properties is needed to minimize uncertainty and cannot help analyze the reasons for low efficiency; It is required to revise the experimental results to the standard or guarantee conditions, which can only be done by using the energy balance method.

Indirect balance measurement method is a method to determine the boiler thermal efficiency by measuring the heat loss of various combustion products and the heat dissipation loss of the boiler. It is also called indirect measurement method, heat loss method or energy balance method. According to the definition of the indirect balance measurement method, we can conclude that the advantages of the indirect balance measurement method are: it can measure the main quantities (flue gas analysis and flue gas temperature) very accurately; The experimental results can be corrected to standard or...
guarantee conditions. Since the measured (various losses) only account for a small share of the total energy, the uncertainty of the efficiency of the experiment is small. The error between the secondary measured value and the estimated value has little influence. The source of the larger loss can be confirmed. The disadvantages of the indirect balance measurement method are: more measurement is needed; Evaporation and output data cannot be obtained automatically; Some losses are actually unmeasurable and their values must be estimated.

Section 5.4 of GB/T 10180-2017 stipulates that the boiler thermal efficiency shall be measured by both the direct balance measurement method and the indirect balance measurement method. The boiler thermal efficiency value shall take the average value of the results measured by the direct balance measurement method and the indirect balance measurement method. However, from the above analysis of the direct balance measurement method and the indirect balance measurement method, it can be seen that the direct balance measurement method and the indirect balance measurement method are two different test methods, and the test contents and test principles are different, so the boiler thermal efficiency tested by the two different test methods cannot be compared. In addition, according to the uncertainty analysis of boiler thermal efficiency made by Zhu Chunmei [2], it can be seen that the uncertainty result of boiler thermal efficiency calculated by the direct balance method is 4.9783, the uncertainty result of boiler thermal efficiency calculated by the indirect balance method is 0.4785, and the uncertainty result of boiler thermal efficiency calculated by the direct balance method and the uncertainty result of boiler thermal efficiency calculated by the indirect balance method are obviously not at the same level. Therefore, no matter from the perspective of testing principle or uncertainty analysis, the author believes that the boiler thermal efficiency should not be the average value of the results measured by the direct balance method and the indirect balance measurement method.

2.2 Test Methods for Condensing Boilers
Section A.2 of Appendix A to GB/T 10180-2017 stipulates that the boiler thermal efficiency calculation for flue gas condensation and heat recovery within the boundary of the boiler thermal balance system is obtained by adding the thermal efficiency η1 of the boiler body and the thermal efficiency η2 of the condenser, wherein the thermal efficiency η1 of the boiler body is calculated in accordance with Chapter 10 of GB/T 10180-2017, and the thermal efficiency η2 of the condenser is calculated by the direct balance method. The method solves the problem that the indirect balance test method cannot be used to test the thermal efficiency of the system where flue gas condensation occurs within the boundary of the boiler thermal balance system in GB/T 10180-2003 "Industrial Boiler Thermal Performance Test Regulations", but there are still some problems in actual application.

This section analyzes the problems of this method from the following aspects:

2.2.1 The thermal efficiency η1 of the boiler body is calculated according to Chapter 10 of GB/T 10180-2017, which requires the flue gas temperature and flue gas composition to be measured at the outlet flue of the boiler body. However, the excess air coefficient at the exhaust flue required by TSG G0002-2010 "Supervision Administration Regulation on Energy Conservation Technology for Boiler" shall be the test data at the boiler outlet flue, and the test position shall be arranged behind the last heating surface of the boiler. Therefore, in order to ensure that the boiler test data meet the requirements of TSG G0002-2010 "Supervision Administration Regulation on Energy Conservation Technology for Boiler" during the test of boiler type products, we need to test the composition of boiler flue gas again in the flue behind the last heating surface of the boiler. This content is not explained in detail in GB/T 10180-2017, and many testers did not notice this problem during the test.

2.2.2 According to the actual situation encountered in the field test, many gas-fired boilers (especially cast aluminum boilers which are currently used more frequently) have condensation phenomenon when the flue gas comes out of the boiler body without installing condensers. In this case, the boiler thermal efficiency test still cannot be carried out by the indirect balance test method, and cannot meet the relevant provisions of subsection (5.4 c) of GB/T 10180-2017;
2.2. In this calculation method, the thermal efficiency $\eta_1$ of the boiler body is the average value of the thermal efficiency of the boiler measured by the direct balance measurement method and the indirect balance measurement method, and the thermal efficiency $\eta_2$ of the condenser is measured by the direct balance measurement method. The calculation method has the problem of chaotic use of two test methods with different levels of uncertainty.

2.3. Boiler thermal efficiency correction method

2.3.1. Correction of inlet air temperature deviation from design value

GB/T 10184-2015 "Performance test code for utility boiler" derives the correction formula of exhaust gas temperature when the inlet air temperature deviates from the design value based on the heat balance of the air heater (assuming that the flue gas side efficiency of the air heater does not change when the inlet air temperature of the air heater changes), and then corrects the boiler thermal efficiency according to the corrected exhaust gas temperature[3]. However, GB/T 10180-2017 does not consider the correction of inlet air temperature deviation from the design value.

2.3.2. Correction of inlet flue gas temperature deviation from design value

At present, GB/T 10184-2015 "Performance test code for utility boiler" aims at the correction of the deviation of inlet flue gas temperature from the design value [4]. When the inlet feed water temperature deviates from the design value, the exhaust gas temperature is corrected, and then the boiler thermal efficiency is corrected according to the corrected exhaust gas temperature.

However, GB/T 10180-2017 gives an empirical correction method. If the deviation between the feed water temperature of the steam boiler and the design temperature exceeds -20 K, the thermal efficiency of the boiler with a difference of -60 K between the two will be converted by one percentage point. For coal-fired hot water boilers without air heater, the difference between the outlet water temperature and the rated temperature -15 K boiler thermal efficiency decreases by 1 percentage point; For oil-fired and gas-fired hot water boilers without air heater, the difference between the outlet water temperature and the rated temperature is -25 K, and the thermal efficiency of the boiler decreases by one percentage point. At present, the author has not found the experimental basis and theoretical basis of the empirical correction method.

2.3.3. Fuel correction

In GB/T 10184-2015 "Performance test code for utility boiler", the corrected losses are calculated by substituting the ultimate analysis and lower heating value of design fuel for corresponding values in all computations. Corrections for fuel are not mentioned in GB/T 10180-2017.

2.4. $q_3$ Calculation in Simple Test of Thermal Efficiency under Operating Conditions

Appendix B.1 of GB/T 10180-2017 refers to table 1 for the values of incomplete combustion loss of gas in the simple test of thermal efficiency of boiler operating conditions.

| Project | Unit | Value |
|---------|------|-------|
| CO      | %    | CO≤0.05 0.05<CO≤0.1 0.1<CO |
| $q_3$   | %    | 0.2 0.5 1 |

In the actual measurement process, many boilers, especially gas-fired boilers, due to poor air distribution adjustment, result in small air distribution volume and large amount of CO production, many reaching more than 1%, some even reaching 10%, and the actual incomplete combustion loss of
gas reaches more than 1%, some even more than 10%. However, according to the values in the table, the incomplete combustion loss of gas can only be taken as 1%, which is quite different from the actual value. In addition, when CO is 0, the incomplete combustion loss of gas in the table is 0.2%, but it is actually 0. There is a big error in calculating the incomplete combustion loss of gas by using the value method, which cannot accurately reflect the actual combustion condition of the boiler[5]. It is suggested to use empirical formula to calculate:

\[ q_3 = 0.11(\alpha_{py} - 0.6) \times 30 \times 2CO \]  

The formula is adopted for calculation, which not only does not increase the workload, but also can more accurately reflect the actual operation of the boiler.

2.5 Calculation of Desulfurization Thermal Efficiency

During the calculation of circulating fluidized bed with desulfurizer added according to appendix I of GB/T 10180-2017, the author found that the excess air coefficient calculated by excess air coefficient after adding desulfurizer in appendix I.3 of GB/T 10180-2017 was wrong. After consulting relevant documents, it is found that the calculation method of excess air coefficient after adding desulfurizer in GB/T 10180-2017 comes from ASME PTC4-2013 Fired Steam Generators Performance Test Code[6]. After comparing and analyzing the relevant calculation formulas in the two standards, it is found that the formulas (I.18), (I.20) and (I.21) in GB/T 10180-2017 are incorrect.

Among them, formula (I.18) is a citation error. ASME PTC4 standard uses excess air rate to represent excess air, the actual delivered air quantity minus the theoretical required air quantity divided by the theoretical air quantity and multiplied by 100 is used as excess air rate. GB/T 10180-2017 uses excess air coefficient to represent excess air, and the ratio of actual used air quantity to theoretical air quantity is used as excess air coefficient. The calculation of excess air coefficient in appendix I of GB/T 10180-2017 confuses the excess air rate with the excess air coefficient, and no relevant conversion has been carried out in the process of quoting the ASME PTC4 formula. Therefore, the correct expression of formula (I.18) should be (2). If there are publishing errors in formula (I.20) and formula (I.21), the correct expressions should be (3) and (4).

\[ \alpha_{ds} = \frac{O_2 \left( m_{og} + 0.795 m_{g_{180}} \right)}{m_{o_{180}} \left( 20.95 - O_2 \right)} + 1 \]  

\[ m_{o_{180}} = \frac{CaCO_3_{ar} \times B_{ds}}{10008.6 \times B} \]  

\[ m_{o_{180}} = \frac{0.1151C_{ar} + 0.3430H_{ar} + 0.0431S_{ar} \left( 1 + 0.5\eta_{SO2} \right) - 0.0432O_{ar}}{28.963} \]  

3. Conclusion

According to the actual working conditions, this paper discusses the problems of boiler thermal efficiency value, condensing boiler test method, boiler thermal efficiency correction method, \( q_3 \) calculation in simple test of thermal efficiency under operating conditions and desulfurization thermal efficiency calculation in GB/T 10180-2017 "Thermal performance test code for industrial boilers", and puts forward personal suggestions. The author thinks that the research on the testing and calculation methods of boiler energy efficiency should be strengthened so that the testing and calculation results can more truly reflect the actual situation of the boiler and better guide the energy saving work of the boiler.
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References
[1] GB/T 10180-2017. Thermal performance test code for industrial boilers. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China.
[2] Zhu C.M. The Economic Performance Index Calculation of Thermal Power Based On Uncertainty Analysis [D]. North China Electric Power University (HeBei), 2010.
[3] Zhu C.W, Yan Z.S. (2011) Discussion on Improvement of Correction Method of Outgoing Gas Temperature in GB10184-88 Codes [J]. Boiler Technology. 42(05): 56-59.
[4] Chang Y.Q, Liu X.M, Qi G.L, et al. (2018) Comparison Research of Chinese Boiler Performance Test Codes and ASME PTC 4-2013 [J]. Journal Of Chinese Society Of Power Engineering, 2018, 38(08): 610-616 + 632.
[5] Cheng J, Xie C.H, Wu J.Q, Chen H. (2013) Relevant Issues of "energy efficiency test and evaluation regulation for industrial boiler" [J]. China Special Equipment Safety, 29(06): 50-51.
[6] The American Society of Mechanical Engineers. ASME PTC 4-2013. Fired Steam Generators Performance Test Codes [S]. New York: The American Society of Mechanical Engineers, 2014.