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Correction of Pressure Drop in Steam and Water System in Performance Test of Boiler

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Abstract. Steam and water pressure drop is one of the most important characteristics in the boiler performance test. As the measuring points are not in the guaranteed position and the test condition fluctuation exists, the pressure drop test of steam and water system has the deviation of measuring point position and the deviation of test running parameter. In order to get accurate pressure drop of steam and water system, the corresponding correction should be carried out. This paper introduces the correction method of steam and water pressure drop in boiler performance test.

1. Introduction
The steam and water pressure drop of boiler is an important evaluation index of boiler performance test. It mainly refers to the pressure drop in the superheated, reheater and economizer of boiler and it is a fine project in the contract of the boiler. Fines are generally measured with 0.01Mpa as the smallest unit of measurement. Therefore, the accurate measurement of steam and water pressure drop is very important.

Due to the limitation of installation condition, the measuring points are generally not installed in the guaranteed position and the measuring device and the measured points are not on the same horizontal plane. At the same time, as the fluctuation of working condition, there exists deviation between the test and design conditions of boiler maximum continue rate (BMCR) in boiler performance test [1].

If the boiler output is greater than the design value of BMCR, the pressure drop of steam and water system will increase; conversely, it will decrease.

Therefore, in order to obtain accurate steam and water pressure drop, it is necessary to correct the measured values.

2. Steam and Water Pressure Drop
The steam and water pressure drop refers to the pressure drop caused by the flow resistance and the gravity pressure difference while the steam and water flow in the boiler and it’s calculated by the inlet and outlet static pressure difference. At present, the main content of assessment of the steam and water pressure drop is total pressure drop from the economizer inlet to the superheater outlet and total pressure drop of heat exchanger.
\[ \Delta p = p_{in} - p_{out} \]  

Where  
\( \Delta p \) = steam and water pressure drop, MPa  
\( p_{in} \) = inlet static pressure, MPa  
\( p_{out} \) = outlet static pressure drop, MPa

The total pressure drop of single phase fluid flow is [2]

\[ \Delta p = \Delta p_{mc} + \Delta p_{j b} + \Delta p_{zw} + \Delta p_{ja} \]  

Where  
\( \Delta p \) = total pressure drop, MPa  
\( \Delta p_{mc} \) = frictional pressure drop, MPa  
\( \Delta p_{j b} \) = local pressure drop, MPa  
\( \Delta p_{zw} \) = gravity drop, MPa  
\( \Delta p_{ja} \) = acceleration pressure drop, MPa

To steady flow, if the pipe diameter is constant, the friction pressure drop is expressed as follows

\[ \Delta p_{mc} = \frac{1}{D} \left( \frac{\rho u^2}{2} \right) \]
Where
\( \bar{\nu} \) = the integral average specific volume along the length of the fluid, \( \text{m}^3/\text{kg} \)
\( \rho_0 \omega \) = mass velocity of the working medium, \( \text{kg/} (\text{m}^2\cdot \text{s}) \)

\( \lambda = \text{frictional resistance coefficient} \)

To single phase fluid, the local pressure drop is expressed as follows

\[
\Delta p_{lb} = \zeta_{lb} \frac{(\rho_0 \omega)^2}{2} \bar{\nu}
\]

(4)

Where
\( \bar{\nu} = \text{specific volume of fluid,} \text{m}^3/\text{kg} \)
\( \zeta_{lb} = \text{local resistance coefficient} \)

To single phase fluid, the gravity drop is expressed as follows

\[
\Delta p_{zw} = \bar{\rho} g \Delta h
\]

(5)

\[
\Delta h = (h_c - h_i)
\]

(6)

Where
\( \bar{\rho} = \text{average density of inlet and outlet working medium in the pipe, kg/m}^3 \)
\( \Delta h = \text{height difference between inlet and outlet of the pipe, m} \)
\( h_c, h_i = \text{inlet and outlet height of the pipe, m} \)

The acceleration pressure drop is expressed as follows

\[
\Delta p_{az} = (\rho W^2)(\bar{\nu}_c - \bar{\nu}_i)
\]

(7)

Where
\( \bar{\nu}_c, \bar{\nu}_i = \text{specific volume of working medium at the inlet and outlet of the pipe, m}^3/\text{kg} \)

To the total pressure drop, the acceleration pressure drop is negligible.

3. **Position deviation correction**

It is the first task of the performance test to make clear the interface of the measuring system and determine the position of the measuring points. Usually, the measuring points are not in the guaranteed position, it is necessary to make corrections.

3.1. **Gravity Difference Correction**

When the measuring device and the measured point are not in a horizontal plane, the correction of the gravity difference which comes from the liquid column in the transfer pipe should be taken into account.

In Figure 1, the pressure gauge or transmitter and the taps are not on the same level, assuming that the Reading of pressure gauge or transmitter1 is \( p_1 \) (MPa), the Reading of pressure gauge or transmitter2 is \( p_2 \) (MPa), uncorrected pressure drop is \( p_1 - p_2 \). The pressure deviation which comes from the liquid column in the transmission pipe is expressed as follows [3]

\[
\Delta p_z = \bar{\rho} g h \times 10^{-6}
\]

(8)
\[ \Delta p_x = \text{additional pressure drop caused by the vertical height of the liquid column in the transmission pipe, MPa} \]

\[ h = \text{vertical height difference between the center point of pressure gauge or transmitter and pressure taking port, m} \]

\[ g = \text{gravitational acceleration, } 9.807\text{m/s}^2 \]

\[ \rho = \text{refrigerant density, kg/m}^3 \]

Where

\[ \text{Figure 2. Gravity difference diagram1.} \]

The corrected pressure drop is:

\[ (p_1 + \rho g H_1 \times 10^{-6}) - (p_2 + \rho g H_2 \times 10^{-6}) \quad (9) \]

Where

\[ H = \text{vertical height difference between the center point of pressure gauge or transmitter and pressure taking port, m} \]

The height difference \( H \) were the relative value, when the pressure gauge or transmitter above tap, the height difference \( H \) is positive; when the pressure gauge or transmitter below tap, the height difference of \( H \) negative. In Figure 1, \( H_1 \) is positive, \( H_2 \) is negative; in Figure 2, \( H_1 \) negative, \( H_2 \) positive.

\[ \text{Figure 3. Gravity difference diagram2.} \]
3.2. Pipeline Resistance correction
Pressure drop guaranteed by boiler plant is usually the drop from the inlet header to the outlet header of the heating surface. Considering convenient construction and instrument installation conditions, pressure measuring points are generally not installed in the header, but installed in the inlet and outlet pipe. There is a distance between the pressure measuring points to the header. This pipeline will certainly produce frictional resistance and there may be elbow, three, orifice plate, test valve etc. between the distances. These components will produce local resistance, in order to obtain the real value of heating surface resistance; the resistance caused by the pipeline should be subtracted.

Take a power plant as an example. The guaranteed steam and water pressure from economizer to drum is 0.392MPa but the measured value is 0.562MPa. By searching the data, we found that there is a long distance between the inlet pressure measuring point and the inlet header of economizer, with elbow, flow orifice, check valve and other components, as shown in Figure 4.

![Figure 4. Diagram of the inlet pressure measuring point.](image)

We should count up the distance between the inlet header of economizer and the pressure measuring point, height difference, radius and quantity of elbow, specifications and materials of the pipe, and then find the resistance coefficient of orifice plate and the valve through checking the table, followed by calculation of pipe resistance and local resistance. Through the calculation, the resistance is 0.229MPa, so the pressure drop after correction is (0.562MPa-0.229MPa=) 0.333MPa, which reached the design value of 0.392MPa.

4. Operating Parameter Deviation Correction
Due to fluctuation of working conditions, the steam flow, pressure, and temperature may be different from the design value, then the physical parameters of the steam will change, and the pressure drop
will change. Assessment tests generally require pressure drop under design parameters; therefore, the deviation of the operating parameters should also be corrected.

4.1. Pressure Drop of Reheater

For the pressure drop of reheater, the gravity pressure drop can be neglected, and it is determined by frictional resistance and local resistance. According to the formula (2) (3) (4), we can get formula (10).

To give reheater, friction coefficient and the local resistance coefficient is constant, the pressure drop is proportional to the square of the steam flow rate, and is proportional to the average specific volume of the steam.

\[
\Delta p_{zt} = \Delta p_{jb} + \Delta p_{zw} \\
= \sum \frac{l \cdot (\rho \omega)^2}{2} + \sum \frac{\xi_{jb} (\rho \omega)^2}{2} \\
= \frac{1}{2} \left( \sum \frac{l}{D} + \sum \frac{\xi_{jb}}{D} \right) (\rho \omega)^2 \bar{u} \\
= \frac{1}{2} \left( \sum \frac{l}{D} + \sum \frac{\xi_{jb}}{D} \right) \left( \frac{G}{A} \right)^2 \bar{u} \\
= kG^2 \bar{u}
\]

(10)

Where

\(A=\text{sectional area of pipeline, } m^2\)
\(k=\frac{1}{2A} \left( \sum \frac{l}{D} + \sum \frac{\xi_{jb}}{D} \right), \text{ constant}\)
\(G=\text{steam flow rate, kg/s}\)

Therefore, the pressure drop can be corrected by the following formula

\[
\Delta p_d = \Delta p_{zw} \frac{\bar{u}_d}{G_d} \left( \frac{G_d}{G_t} \right)^2
\]

(11)

\(\Delta p_d = \text{operating parameter deviation correction, MPa}\)
\(\Delta p_{zw} = \text{position deviation correction, MPa}\)
\(\bar{u}_d = \text{design average specific volume, } m^3/kg\)
\(\bar{u}_t = \text{test average specific volume, } m^3/kg\)
\(G_d = \text{design steam flow rate, kg/s}\)
\(G_t = \text{test steam flow rate, kg/s}\)

4.2. Pressure Drop from Economizer to HP Superheater Outlet

To the pressure drop from the inlet of economizer to the outlet of HP superheater, due to the phase transition of the working fluid (water in the economizer, steam and water in the water wall, superheated steam in the superheater), it is necessary to make subsection correction in order to get accurate results. The working fluid in the economizer is liquid water, the pressure drop mainly comes from the gravity pressure drop, and the change of the working condition has little influence on it, and the error can be ignored.

When the precision requirement is not high, the gravity pressure difference of the economizer can be deducted on the basis of the correction of the position deviation of the pressure measuring point, and then do operating parameter deviation correction according to the formula (11). The final pressure drop is equal to the sum of the correction result and the gravity pressure difference of the economizer.
Another correction formula is given in reference [4], which can be corrected only according to the flow rate, and the result is similar to the result of formula (11).

\[ \Delta p_d = \Delta p_{wz} \left( \frac{G_d}{G_t} \right)^{1.7} \]  

(12)

5. Calculation Example

In the actual calculation, correction of steam and water pressure drop should be carried out according to the following steps. First, the measured static pressure difference can be obtained according to the formula (1), and then the position deviation correction of measuring points should be carried out. Finally, the operation parameter deviation is corrected and we can get the final result. Table 1 is calculation of the steam and water pressure drop of the reheater.

| Item | Unit | Value |
|------|------|-------|
| G_d-design steam flow rate | t/h | 2455.80 |
| p_{d_in}-design inlet pressure | MPa | 6.17 |
| p_{d_out}-design outlet pressure | MPa | 5.98 |
| t_{d_in}-design inlet temperature | ℃ | 362.00 |
| t_{d_out}-design outlet temperature | ℃ | 623.00 |
| G_t-test steam flow rate | t/h | 2329.80 |
| p_{t_in}-test inlet pressure | MPa | 5.74 |
| p_{t_out}-test outlet pressure | MPa | 5.53 |
| t_{t_in}-test inlet temperature | ℃ | 354.00 |
| t_{t_out}-test outlet temperature | ℃ | 614.00 |
| \( \bar{\eta}_d \)-design average specific volume | m³/kg | 0.055 |
| \( \bar{\eta}_t \)-test average specific volume | m³/kg | 0.059 |
| \( \Delta p \)-measured static pressure difference | MPa | 0.203 |
| pressure drop from inlet pressure extraction point to header | MPa | 0.047 |
| pressure drop from outlet pressure extraction point to header | MPa | 0.006 |
| pressure drop from inlet measuring point to transmitter | MPa | 0.020 |
| pressure drop from outlet measuring point to transmitter | MPa | 0.020 |
| \( \Delta p_{wz} \)-position deviation correction | MPa | 0.110 |
| \( \Delta p_d \)-operation parameter deviation correction according formula (11) corrections | MPa | 0.114 |
| \( \Delta p_d \)-operation parameter deviation correction according formula (12) corrections | MPa | 0.089 |

6. Conclusion

This paper introduces the correction method of steam and water pressure drop in boiler performance test. The position deviation correction of measuring points and correction of operation parameter deviation are necessary.

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