Experiment Comparison between Engineering Acid Dew Point and Thermodynamic Acid Dew Point

Jinghui Song[1], Hui Yuan[2]， jianhua Deng[1]

[1]Guangdong Power Grid Co., Ltd. Electric Power Research Institute, Guangzhou 510000,China
[2]North China Electric Power University (Baoding), Baoding 071000,China；

Abstract：in order to realize the accurate prediction of acid dew point, a set of measurement system of acid dew point for the flue gas flue gas in the tail of the boiler was designed and built, And measured at the outlet of an air preheater of a power plant of 1 000 MW, The results show that: Under the same conditions, with the test temperature decreases, Nu of heat transfer tubes, fouling and corrosion of pipe wall and corrosion pieces gradually deepened. Then, the measured acid dew point is compared with the acid dew point obtained by using the existing empirical formula under the same coal type. The dew point of engineering acid is usually about 40 ℃ lower than the dew point of thermodynamic acid because of the coupling effect of fouling on the acid liquid, which can better reflect the actual operation of flue gas in engineering and has certain theoretical guidance for the design and operation of deep waste heat utilization system significance.

1 Introduction

With the continuous improvement of the national energy-saving and emission reduction targets, it is urgent to reduce the temperature of the boiler exhaust gas and improve the utilization of the tail flue gas waste heat [1]. Excessive flue gas temperature is not only not conducive to the improvement of boiler efficiency, but also increases the risk of boiler failure. Studies have shown that the boiler efficiency can be increased by 0.6% -1.0% for every 10°C reduction in boiler tail flue gas temperature [2] However, the boiler exhaust gas temperature can not be reduced, when the exhaust gas temperature is too low, the heat exchanger is operated under the acid dew point of the flue gas, the SO_3 in the flue gas will form a H_2SO_4 droplet with the condensed water vapor, Low temperature corrosion and ash deposition on the surface will inevitably increase the flow resistance of the flue gas and decrease the heat transfer efficiency [3]. Therefore, the acid dew point is the key index restricting whether coal-fired power plants can utilize the waste heat of the tail flue gas in depth.

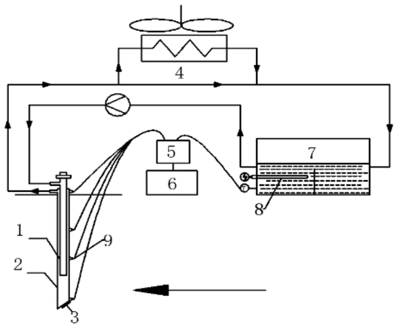
At present, domestic and foreign institutions for the study of low temperature corrosion and acid dew point can be divided into two categories: a class of empirical formula focusing on the acid dew point [4], such as China's power industry commonly used in the former Soviet Union Computational Standard Method "empirical estimation formula, which is based on experimental data of All-in-one Institute of Thermal Engineering in the 1950s. It is mainly applied to solid and liquid fuels. In 1959, Muller [5] based on the mixture of SO_3 and H_20 In the gas phase system, the acid dew point curve of flue gas containing low concentration of H_2SO_4 vapor is obtained by using the thermodynamic theory. The other type focuses on the acid dew point corrosion test bench for building simulated flue gas The simulation results show that the law of acid corrosion and the acid dew point of flue gas come into being. For example, two different kinds of flue gas acid dew point measuring devices have been designed and designed by Bai Xiang [6]. The acid dew point under different flue gas conditions were measured, The results show that with the increase of partial pressure of sulfuric acid vapor or steam in the flue gas, the change trend of acid dew point of flue gas gradually slows down. Although the acid dew point obtained by these two methods can prevent boiler tail replacement Surface is subject to the risk of low temperature corrosion, but its design reliability parameters are too high, can not truly reflect the dew point characteristics of coal-fired flue gas, that is, within a certain range of thermodynamic acid dew point containing acid ash particles did not show the film should Sediment characteristics, and therefore has some limitations. Shi Yuetao, Shandong University [7] put forward the concept of engineering acid dew point for the first time. Compared with the traditional thermodynamic acid dew point, express the influence law of acid condensation on the heat exchanger in ash-containing gas flow and enlarge the low temperature waste heat temperature range.

Based on the experimental study of acid dew point, a set of new experimental system of acid dew point measurement for flue gas was established in this paper. The casing with corrosion sheet was used as the experimental section to measure the acid dew point of the air preheater exit of a power plant. In addition, the article also compares the measured acid dew point with the acid dew point calculated from each empirical formula under the same coal conditions.

2 engineering acid dew point test system and calculation method

2.1 Test System

The entire project acid dew point measurement system consists of three parts: water temperature system, test section, measurement and acquisition system. Experimental system diagram shown in Figure 1.



1-inner sleeve; 2-outer sleeve; 3-corrosive sheet; 4- air-cooled coil;
5- temperature recorder; 6- control cabinet; 7- constant temperature water tank; 8- electric heating pipe;

Figure 1 Engineering acid dew point measurement test system diagram

The test section is a double-sleeve structure, as shown in Figure 2, which can be installed in the tail flue measuring hole. The device has a simple structure, including an inner sleeve, an outer sleeve, inlet and outlet water pipes and corrosion patches. The measuring device has three sets of cannulas (length of 69cm, 79cm and 89cm, respectively), which can conduct research on the performance of low-temperature corrosion at different depths of the same position of the flue respectively; the top of each cannula is connected with the ND steel corrosion- The inner casing of the gun casing is connected to the outlet section of the circulating pump through the plastic hose and the radiator casing is connected to the outlet of the casing. The bent pipe is used to cool the working medium in the pipeline with air to ensure the constant inlet water temperature.

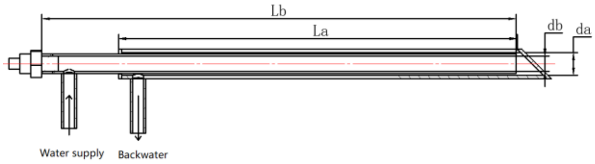


Figure 2 Test section device diagram

The main targets of the data acquisition system are the temperature points, including the temperature measurement points of the corrosion wall on the test section and the temperature measurement points on the water return pipeline and the water tank, the temperature data collected by the temperature recorder is directly reflected on the control cabinet test interface, Through the control system can set the tank temperature, return water temperature and electric heating pipe.

2.2 test process

The test point selection of a power plant 1 000 MW ultra-supercritical coal-fired turbine generator air preheater outlet to the entrance of the low-pressure economizer horizontal flue. During the test, the load of the unit is stable at 1 000 MW. At the beginning of the test, the electric water heater and the fan are started and the circulating pump is turned on to preheat the test piece to 80°C. Then, the test piece heat exchanger tube and the corrosion piece are inserted Test hole and sealed with cotton cloth, to prevent leakage of air.

In the control cabinet were set heat exchanger wall temperature, observe and record the test temperature, when the test section in the flue gas flue gas after 2h, the test section is pulled out, the first observation and recording of corrosion and heat exchangers wall area gray and corrosion The weight of the fly ash deposited on the wall of the heat exchange tube at the temperature was weighed and the heat transfer tube Nu was calculated at the temperature. The corrosive sheet was taken out of the top of the smoking gun and placed on the numbered A4 paper, respectively, Test paper on the surface of the corrosion test piece of acid to observe the discoloration of the pH test paper and compared with the original pH paper, if the pH test paper no discoloration, the temperature point is not in the flue gas acid dew point range, polished corrosion sheet to the clean state, the test Section back into the flue, the other conditions remain unchanged, lower the wall temperature of the heat transfer tube, repeat the above steps until the end of the test, draw the heat transfer wall sediment weight and Nu with the outer wall temperature curve, and finally according to Nu number Interval and pH test paper color change, get the project acid dew point roughly change range.

2.3 Theoretical Calculation

Test tube section and high temperature flue gas convection heat transfer, and the heat transfer to the water, test tube enhanced heat transfer characteristics can be Nu number to represent, as follows:

$$Nu = \frac{\mathrm{h} \times \mathrm{d_a}}{\lambda} \quad (1)$$

Where da is the outer diameter of the outer tube of the heat exchange tube, h is the convective heat transfer coefficient of the heat exchange tube, and λ is the thermal conductivity of the flue gas.

Heat exchange tube flue gas side convection heat transfer:

$$Q_y = hA\Delta t = hA(t - t_a) \quad (2)$$

Where Qy is the heat absorption on the flue gas side, A is the wall area of the heat transfer outer pipe, t is the flue gas temperature, and ta is the temperature of the wall of the heat transfer outer pipe.

 https://doi.org/10.1051/e3sconf/20183804008

Exchange heat pipe water side convection heat transfer:

$$Q_S = C_p m \Delta t = C_p m (t_{out} - t_{in}) \quad (3)$$

Cp is the specific heat of circulating water, m is the circulating water quality flowing through the heat exchange tube in unit time, tout is the backwater temperature, and tin is the feed water temperature.

Heat transfer tube wall area:

$$A = \pi \times d_a \times l_0 \quad (4)$$

Since the entire heat exchange process is in steady state, the heat exchange on the flue gas side is equal to the heat exchange on the water side. which is:

$$Q_y = Q_s \quad (5)$$

By the formula (1) ~ (5), finishing can be obtained Nu number:

$$Nu = \frac{C_p m d_a (t_{out} - t_{in})}{A\lambda(\text{t-}t_a)} \quad (6)$$

3 test results and discussion

3.1 wall sediment weight and Nu number changes with the outer wall temperature

After each experiment, different wall temperature heat pipe fouling was weighed, sediment weight and wall temperature under different theoretical calculations obtained Nu tube circulating water number changes as shown in Figure 4. As can be seen from the figure, as the outer wall temperature decreases, the Nu number of the heat transfer tube decreases, the weight of the outer wall sediment increases, and the Nu number falls sharply with the outer wall temperature in the 67~72℃ and 55~60℃, The temperature of the sediment rising steeply with the outer wall temperature is in the range of 67-72℃, indicating that a large amount of fly ash is deposited on the wall of the heat exchange tube during the temperature interval, and the thickness of the fly ash layer increases sharply, resulting in increased heat transfer resistance of the heat exchange tube, Greatly affecting the heat transfer performance, resulting in deterioration of the heat transfer tube heat transfer characteristics.

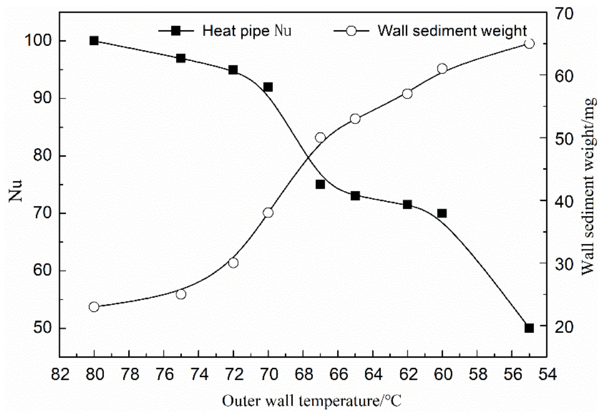
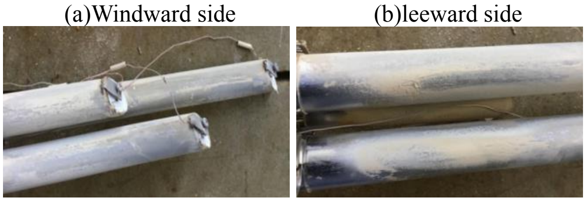


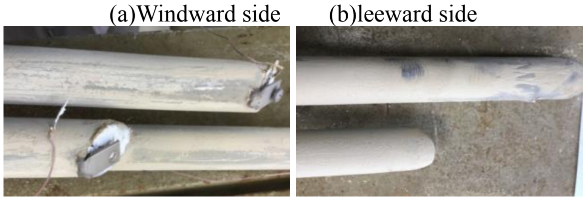
Figure3 wall temperature on the heat transfer tube heat transfer characteristics

In general, when the coal species and combustion conditions remain unchanged, the low-temperature economizer inlet flue ash concentration does not change much, when the wind speed is constant, the ash to achieve a dynamic balance, does not Infinite increase, that is, 80℃~72℃ temperature range, the thickness of fouling stabilized at a certain value. When the outer wall temperature dropped to 72~67℃, the number of Nu sharp decline, and the fly ash contains a lot of water vapor and acidic substances, which can be judged in the temperature range, due to lower smoke temperature, fly ash and flue gas The acid-ash coupling phenomenon occurs in the precipitated sulfuric acid vapor, resulting in the further increase of the thickness of the ash layer. As shown in Fig. 4, the ash of the pipe wall area varies at three different temperatures. First, at 80°C, the windward and leeward surfaces of the pipe wall are clean , And good heat transfer capacity; and then reduce the wall temperature to near 70°C and found that the surface of the heat exchange tube surface appeared dry ash, but there is no evidence of corrosion, can be removed by a simple soot blowing, indicating that at this temperature a small amount of sulfuric acid vapor condensation , Wall heat transfer capacity began to decline; continue to reduce the wall temperature to 60°C, can be found in the windward and leeward surface of the pipe are a large number of cohesive fouling, and windward ash more difficult to remove, indicating that the temperature, smoke A large amount of sulfuric acid vapor is precipitated in the gas, and the sour ash is coupled with the ash, which greatly affects the heat transfer capacity of the heat exchange tube, thus indicating that the temperature near the temperature has changed within the range of the acid dew point. , The heat exchange tubes should avoid the wall temperature condition, to prevent acid corrosion.

(a)Windward side (b)leeward side



(a)Windward side (b)leeward side



(a)Windward side (b)leeward side

Figure4 Pipe wall gray area conditions in the temperature of 80℃/ 70℃/ 60℃

3.2 Corrosive pieces of fouling and pH test paper test phenomenon

Figure 5 (a) shows the initial corrosion sheet before the experiment, the surface is smooth, and Figure 5 (b) (c) (d) shows the corrosion after two hours of flue gas scrubbing at three sets of temperature The pictures of the pH test strips and the pictures of the pH test strips after the test show that the degree of acid ash adhesion on the surface of the corrosion strips gradually increases and the color of the pH test strips changes from shallow to deep.

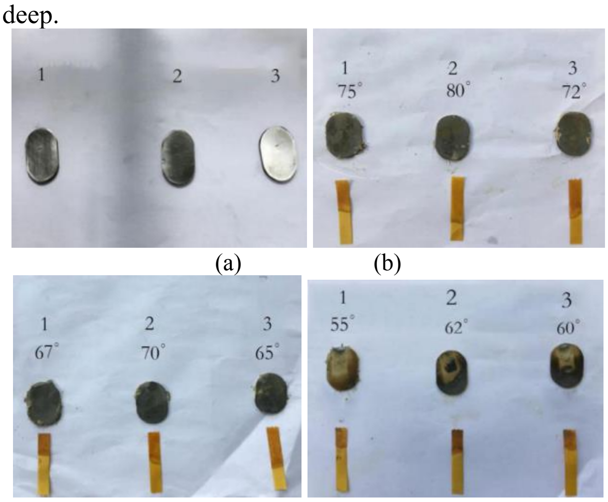


Figure 5 the situation of corrosion sheet and test paper discoloration in different groups of temperature

By observing the corrosion condition of the corrosion sheet at the temperature of 72°C/75°C/80°C in Figure 5(b), it is not difficult to find that the corrosion condition of the corrosion sheet at this temperature point is not much different from that in Figure 5 (a) Gray, scratched ash layer is difficult to observe the corrosion with the naked eye, compared to pH discoloration test conditions, we can find 75℃ and 80℃ pH test paper almost no discoloration, and 72℃ pH test paper began to occur slight discoloration, indicating at 72℃ A small amount of sulfuric acid vapor was precipitated in the flue gas, but most of them were absorbed by the ash particles in the flue gas. As a result, the surface of the corrosion sheet did not show any signs of corrosion. However, when the temperature was further lowered to the second set of temperature points (65°C/67°C/70°C) and the third set of temperature (55/60℃ /62℃), it can be clearly observed that the corrosion degree of the corrosion sheet surface is gradually aggravated, the thickness of the ash layer is increased, and the color of the pH paper is deepened. Further reducing the amount of precipitated sulfuric acid increased significantly, while the ability of ash particles to absorb acid tends to saturation, acid and ash at this time the acid-ash coupling phenomenon, making the surface ash viscosity changes, the balance of the ash is broken, and thus corrosion Sheet surface Knot of constantly fouling and thickening occurs more severe acid corrosion.

Based on the above analysis of the Nu number of different tube wall temperature, the gray area of the wall of the heat exchange tube, the surface corrosion phenomenon of the corrosion sheet and the acidity of the pH test paper, it shows that when the test tube section is at 72°C. and above, However, the heat transfer characteristics of the heat transfer tube did not deteriorate, and no corrosion occurred on the heat transfer tube and the surface of the corrosion film, indicating that most of the sulfuric acid vapor in the flue gas is absorbed by the fly ash at this time However, when the wall temperature of test pipe section is lower than 72℃, Nu number of heat exchange tube will drop sharply and acid corrosion of pipe wall and corrosion plate will occur. The heat transfer characteristics will be deteriorated, which shows that the power plant Air preheater exit tail flue engineering acidity point in the vicinity of 72℃.

4 different acid dew point comparison results and bias analysis

The power plant boiler coal quality analysis and design conditions tail flue raw data in Table1,Table 2.

Table1 Analysis of coal quality and ash analysis of the power plant

heading	M_t	Mad	Aad	Vad	FCad	St,ad	Qnet,ar
data	20.2%	10.94%	11.08%	29.56%	48.42%	0.58%	20.60 MJ/Kg

Table 2 Original data for the tail flue under the design of the plant

heading	V_{H_2O}	P_{H_2O}	α	V_{SO_2}	P_{SO_2}	P_{SO3}
data	9.91	10042.1	194.00	0.0155	15.76	0.322

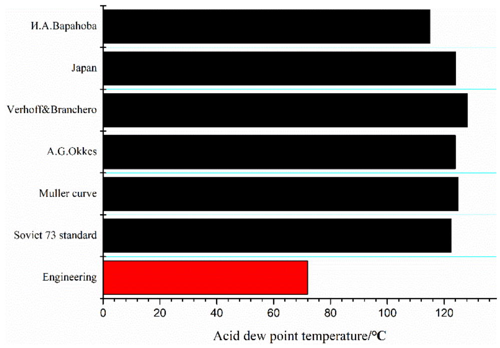


Figure 6 Engineering acid dew point and thermodynamic acid dew point comparison

Engineering acid dew point and thermodynamic acid dew point calculation formula obtained by the comparison of the calculated results shown in Figure 6, can be seen from the figure, the selected thermodynamic acid dew point formula is not much difference, were maintained at 120℃ up and down, but are far Engineering acid dew point under the same coal combustion conditions, the formula listed in the calculation of acid dew point and project acid dew point minimum error of 39 ℃, the maximum error of 53℃, resulting in engineering acid dew point far lower than the thermodynamic acid dew point is the actual operation The composition of ash in boiler flue gas is complex.

When the flue gas temperature decreases, a large amount of gas phase components such as $SO_3/H_2O/H_2SO_4$ contained in the fly ash are precipitated. These components can easily diffuse to the surface or pore of fly ash particles, Physical adsorption, and SO_3/H_2SO_4 and fly ash Ca and Mg and other alkaline oxides between the chemical adsorption, resulting in acid-ash coupling phenomenon, resulting in the SO_3 vapor content in the flue gas greatly reduced compared to Under the traditional thermodynamic acid dew point, the complicated flue gas is often simplified as the ideal mixture of SO_3 and H_2O, ignoring the effect of ash in the flue gas on acid dew point, thus making the engineering Acid dew point is generally lower than the thermodynamic acid dew point.

5 Conclusion

In this paper, a new set of acid dew point measurement system for flue gas project was established. Field experiments were carried out on the tail flue of a 1 000 MW power plant. Using the thermodynamic method, the variation law of Nu number and wall temperature of circulating water in the pipe was studied. Different pipe wall temperature, analysis of fouling and the condensation of sulfuric acid vapor on the heat transfer performance of the heat exchange tube, the acid dew point of the project fluctuates around 72℃, that is the temperature at which Nu number plunges for the first time, and the resulting project acid dew point The results show that the acid dew point of the project is at least 39℃ lower than the thermodynamic acid dew point. Finally, the reasons for the deviations between the measured and calculated results are analyzed. The results show that Engineering acid dew point in practical engineering application value, the design of the power plant low temperature economizer heat exchanger cold water inlet temperature should be controlled as much as possible above 72℃, to guide the boiler tail flue gas deep waste heat utilization system design and operation of a very Significance.

References

1. LI Jun, Yan Weiping, Gao Baotong, *et al*. The Calculation of the Gas Acid dew-point in Utility Boiler. Boiler Technology, 2009; 40 (5): 14-17
2. Xiang B, Zhang M, Wu Y, et al. Experimental and modeling studies on sulfur trioxide of flue gas in a coal-fired boiler. Energy & Fuels, 2017; 31(6): 6284-6297
3. Li Pengfei, Tong Huiling. Comparison and Analysis on the Calculation Methods of Acid Dew Point of Flue Gas. Boiler Technology, 2009; 40 (6): 5-8
4. Tang Zhiyong, Jin Baosheng, Sun Keqin, et al. The contrast and evaluation of the calculation formulas of acid dew point temperature of the flue gas after the WFGD. Journal of Power Engineering,2005: 18-21
5. Muller P. Contribution to the problem of the effect of sulphuric acid upon the dew-point temperature of flue gas. Chem.Eng.Tech., 1959; 31: 345-390
6. Xiang Bai Xiang, Zhao Congzhen, Ding Yanjun, et al. Measurement and prediction model for theacid dew point in flue gases. Journal of Tsinghua University (Science and Technology), 2015; (10):1117-1124
7. Shi Yuetao, Zhang Xiangyu, Li Fei, et al. acid dew pointand other projects-a new criterion for the use of low temperature waste heat boiler limit. Chinese Science Bulletin, 2014; (28): 2810-2816