Leakage failure analysis of water wall tube in circulating fluidized bed boiler

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Abstract. This paper analyzes the causes of water wall tube leakage failure in circulating fluidized bed boiler. According to the results of chemical analysis, the water wall meets the technical requirements. The difference of pearlite spheroidization degree in different regions indicates that there are different degrees of overheating in each region. The energy spectrum analysis of the surface residue in the perforation area shows that the corrosion in the perforation area is related to scale deposition.

1. Introduction

In the power plants, early prediction of furnace tube explosion, timely detection of leakage, and determination of leakage location before explosion are of great significance for the correct implementation of shutdown procedures, shortening maintenance time and minimizing economic losses. The correct failure mechanism is usually helpful for meaningful life assessment and prevention of tube failure in the future.

In the past years, failure causes of boiler water wall tubes have been studied. Jin et al. [1] studied the early high temperature corrosion behavior of 20G and 12Cr1MoV water wall tubes. The effects of material, temperature and various atmospheres on the high temperature corrosion behavior were analyzed. The results show that the corrosion kinetics of the two materials obeys parabolic law. Xiong et al. [2] studied the high temperature corrosion behavior of water wall tubes of 300MW units. The results show that the corrosion products contain a lot of iron and sulfur elements, which belongs to typical sulfide corrosion. Duarte et al. [3] studied the leakage failure behavior of water wall tubes in a water tube boiler. The results show that the tensile residual stress and the concentration of dissolved oxygen in the feed water are too high, which are the main reasons for the premature failure of stress corrosion cracking of boiler tubes. Ahmad et al. [4] analyzed the failure mechanism of water wall tubes of a boiler. The results show that the failure mechanism of water wall tube is hydrogen damage. Lai et al. [5] analyzed the deposition corrosion mechanism of water wall tubes in municipal solid waste grate incinerator. The results show that chloride and alkali metal compounds accelerate the corrosion rate of metal surface through active oxidation mechanism. Zhang et al. [6] proposed a real-time method to determine the location of water wall tube leakage based on acoustic array three-dimensional space positioning algorithm. The results show that this method can accurately locate the leakage area during the coal-fired boiler hot operation. Hao et al. [7] studied the flow and heat transfer of supercritical water in water wall tubes of supercritical boilers by numerical simulation. The results show that the buoyancy effect and the decrease of thermal conductivity of supercritical water will lead to the deterioration of heat transfer.
2. Macroscopic morphology
The macroscopic morphology of the accident section of the intercepted water wall tube is shown in Fig. 1. Relevant data show that the material of the water wall tube is 20G. After measurement, the outer diameter of the water wall tube is about 60mm, and the wall thickness is about 7.2mm. The damage of the sample was distributed in the fire side, showing a large penetrating hole. From the two ends of the cut-off surface, there is no abnormal uneven thinning of the tube at both ends and two facing directions. The outer surface of the back side and the fire side was smooth without abnormal macroscopic damage. The inner wall of fire side was corroded seriously. The inner wall of the back side is relatively smooth and white stuff is found.

![Image of macroscopic morphology of the water wall tube](image1)

Figure 1. Macroscopic morphology of the water wall tube.

The macroscopic morphology of the fire side outer surface of the perforation damage zone is shown in Fig. 2. It can be seen that the outer surface of the tube is relatively smooth, and no obvious deformation and obvious macroscopic corrosion signs are found. The length and width of the perforation on the outer surface are about 22.9mm and 18.7mm respectively. The thickness of the thinnest part of the hole edge is about 1mm.

![Image of macroscopic morphology of fire side outer surface](image2)

Figure 2. Macroscopic morphology of the fire side outer surface of the perforation damage zone.

The macroscopic morphology of the inner surface in the perforation area is shown in Fig. 3. It can be seen that the inner surface fluctuates greatly, and there is layer peeling phenomenon, which gradually thins to the hole edge. The length of the perforation on the inner surface is about 21.5mm and the width is about 13.9mm. There are two longitudinal cracks extending from the edge of the hole at the inner surface, with the length of 13.3mm and 16.8mm respectively.

![Image of macroscopic morphology of inner surface](image3)
3. Results and Discussions

3.1. Chemical composition analysis
The results of chemical composition analysis are shown in Table 1. According to the chemical analysis results, the material of the water wall tube meets the technical requirements of 20G in GB/T 5310-2017 < Seamless steel tubes and pipes for high pressure boiler >.

Table 1 Chemical composition of the water wall tube (wt.%).

| Element | C   | S   | Si  | Mn  | P    | Cr | Ni | Cu |
|---------|-----|-----|-----|-----|------|----|----|----|
| Tube    | 0.20| 0.015| 0.22| 0.47| 0.016| 0.025| 0.008| 0.005|
| 20G (GB/T 5310-2017) | 0.17-0.23 | ≤0.015 | 0.17-0.37 | 0.35-0.65 | ≤0.025 | - | - | - |

3.2. Metallographic microstructure analysis
The micromorphology of the cross section of the hole edge of the water wall is shown in Fig. 4. The upper side of the figure is the outer surface, and the surface is flat. The lower side is the inner surface, which is uneven, with corrosion pits and corrosion products. At high magnification, the microstructure at the edge of the hole is ferrite and pearlite. Pearlite has been spheroidized, and the spheroidization grade can be rated as grade 4, which is due to high temperature. The microstructure of the cross section far away from the hole is ferrite and pearlite. Most of pearlite remains lamellar and the degree of spheroidization is not high.

Figure 3. Macroscopic morphology of the inner surface in the perforation area.

Figure 4. Micromorphology of the cross section of the hole edge.

The longitudinal section morphology of the crack near the hole is shown in Fig. 5. It can be seen that the two sides of the crack are not matched, there are corrosion pits of different degrees, and there are oxidation layers attached. The structure tends to strip segregation along the axial direction. At high
magnification, some pearlite is spheroidized, and oxide layer is attached on the crack surface with a thickness of about 30.28μm, as shown in Fig. 5(b).

![Figure 5. Micromorphology of the longitudinal section of the crack.](image)

3.3. SEM Micromorphology analysis
The SEM micromorphology of the perforation edge is shown in Fig. 6. It can be seen from the morphology at low magnification as shown in Fig. 6 (a) that the surface of the hole edge is relatively rough, covered with corrosion, and there are traces of scouring and rheology, and cracks extending along the longitudinal direction starting from the hole edge. The morphology of the hole edge at high magnification is shown in Fig. 6 (b), and the surface is covered with corrosion products. There are also axial cracks on the surface of the corrosion products.

![Figure 6. SEM morphology of the perforation edge.](image)

The X-ray energy spectrum analysis of the corroded surface is shown in Fig. 7 (a). It can be seen that in addition to the main elements, Cl (about 0.16%), S (about 0.40%), Ca (about 2.35%) and other elements can be seen, indicating that the corrosion is related to scale. The X-ray energy spectrum analysis of the white stuff on the surface is shown in Fig. 7 (b). The peak lines of O (about 60.42%), Ca (about 36.00%) and S (about 1.31%) are visible, indicating that the white stuff is scale.

![Figure 7. X-ray energy spectrum analysis of the corroded surface.](image)
4. Conclusion
Based on the macroscopic and microscopic analysis, it can be concluded that the corrosion perforation of the sample is caused by local abnormal deposition of scale. Due to the accumulation of scale, the tube is overheated and deviates from the normal PH value. The water will gradually concentrate into corrosive medium under the scale, resulting in tube wall corrosion. At the same time, due to the overheating of the area, the strength of the body decreases and the longitudinal cracking occurs with the thinning of the tube wall.

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