Failure Analysis on Leakage of Brass Condenser Tube in Thermal Power Plant

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Abstract. The corrosion failure analysis of the brass tube in a power plant condenser was conducted by the methods of chemical composition analysis, macro morphology inspection of the leakage point, metallurgical examination, scanning electron microscope and energy spectrum analysis etc. The results indicated that the failure of the brass tube was due to the erosion of the internal surface. The zinc content in the etching pits decreased obviously and dezincification corrosion could be classified. Some suggestions for anti-corrosion measures of the brass tubes were put forward.

1. Introduction
The main task of condenser is to condense the exhaust steam of the condensing steam turbine into water, and establish and maintain a certain degree of vacuum at the steam exhaust port of the steam turbine[1]. It is the most important auxiliary equipment for the steam turbine generator set. The reliability of the condenser and its accessories is generally considered to affect up to 3.8% of the generator set availability[2]. Once the condenser cooling tube is deposited, the thermal conductivity of the cooling pipe will decrease, and the heat transfer efficiency of the steam system and even the efficiency of the entire steam turbine unit will decrease[3]. In particular, the cooling pipe will be corroded or even leaked, causing the cooling water to leak into the condensate, deteriorating the quality of condensate water, causing corrosion and scaling of the system, boilers and steam turbines in front of the furnace and even seriously affecting the safety and economic operation of the entire power plant[4, 5]. In a thermal power plants, the service life of the condenser pipe directly affects the operation status of the unit and the boiler[6]. However, the leak of the condenser is not detected in time, or the deterioration of the condensed water quality has not been monitored in some cases, the power plant will be seriously damaged. The quality of the condenser pipe, especially its corrosion resistance and anti-fouling performance, is of great significance for ensuring the safety and economic operation of the power plant, as well as the thermal economy and operational reliability of the entire power plant[7].

The condenser tube of the power plant adopts HSn70-1A brass with a specification of Φ25×1mm. In March 2017, a number of brass condenser tubes were found to leak, and the macroscopic appearance of the leak points was similar. In order to ensure the safety of the condensate gas and prevent the water pollution caused by the leakage accident, this paper analyzes the causes of corrosion and leakage of the copper tubes.
2. Experiment and analysis

2.1. Macroscopic analysis
The macroscopic morphology of the leaked brass condenser tube that leaked is shown in Figure 1. The wall of the pipe is uniform in thickness, without obvious thinning, and there are slight scratches on the outer wall, at the same time, a corrosion perforation about 1.5mm in diameter can be seen. The tube wall in the 1-2 mm area around the perforation was reddish brown, and the remaining tube walls were dark brown. The copper tube was cut longitudinally, and the inner wall surface is shown in Figure 2. It can be seen that the inner wall is uneven, and there are many ulcer-like corrosion pits. Some of the corrosion pits are close to the penetrating state, and the corrosion products are reddish brown and loose.

2.2. Chemical composition analysis
A copper tube was flattened into a chemical composition sample, and the chemical composition of the sample was analyzed by a DV-6 quantitative direct reading spectrometer. The results are shown in Table 1. The material composition of the failed copper tube meets the requirements of HSn70-1A according to the GB/T 5231-2012.

| Sample No.                | alloy element (%) |
|---------------------------|-------------------|
|                           | Cu    | Sn    | As    | Fe    | Pb    | Zn    |
| Leaked brass tube         | 70.02 | 0.98  | 0.038 | 0.006 | 0.003 | 26.95 |
| HSn70-1A                  | 69.0-70.1 | 0.8-1.3 | 0.03-0.06 | ≤0.10 | ≤0.05 allowance |
2.3. Metallographic examination

The metallographic examination was carried out in the circumferential direction near the corrosion pit of the inner wall. As shown in Figure 3, the matrix is α-solid solution, the crystal grains are fine and evenly distributed, and a large amount of twin crystals are contained therein. The edges of the corrosion pit are sawtooth and visible along the crystal micro crack, which is formed from the inner wall and spreads to the outer wall.

![Figure 3. Metallographic structure around the pit](image)

2.4. Scanning electron microscopy and energy spectrum analysis

The surface and internal morphology of the pit were observed under a scanning electron microscope. As shown in Figure 4-5, microcracks extending along the crystal were observed at the edge of the corrosion pit and the inner and outer surfaces.
The energy spectrum analysis was carried out on the brass tube substrate and the bottom of the corrosion pit. The specific position and corresponding energy spectrum are shown in Figure 6-8. The main elements of different detection sites are shown in Table 2. It can be seen from the table that the content of Cu in the cross-section matrix is 69.30%, and the content of Zn is 28.73%, which is consistent with the composition of HSn70-1A. At the bottom of the corrosion pit, the content of Zn is only 5.39%, which is much lower than that of HSn70-1A alloy. The Zn content indicates that the
dezincification of the corrosion site is obvious. The surface of the bottom of the pit presents visible granular corrosion, and its elemental composition is mainly O and Ca.

Figure 6. Brass tube matrix energy spectrum

Figure 7. The bottom spectrum of the corrosion pit

Figure 8. Energy spectrum of granular corrosion at the bottom of corrosion pit

Table 2. Main element content of different detection parts of brass condenser tubes (wt.%%)

| Element               | O   | Ca | Fe | Cu  | Zn | Mg | Sn | P | S | Cl |
|-----------------------|-----|----|----|-----|----|----|----|---|---|----|
| Matrix material       | 1.14| -  | -  | 69.30| 28.73| -  | 0.84| - | - | -  |
| Corrosion pit bottom  | 6.53| -  | -  | 87.65| 5.39 | -  | -  | - | - | 0.43|
Granular corrosion at the bottom of the corrosion pit

|          | 42.07 | 31.89 | 0.45 | 5.25 | 3.93 | 1.3 | 14.1 | 0.6 |
|----------|-------|-------|------|------|------|-----|------|-----|

3. Cause analysis
The macroscopic morphology shows that the outer wall of the brass tube of the condenser is relatively smooth, only slightly scratched, no cracks and corrosion marks, and the inner wall of the tube is corroded obviously. There are many ulcer-like corrosion pits, and the leaked spots on the outer wall are caused by the corrosion pit formed on the inner wall, which gradually penetrates the tube wall. The energy spectrum of the brass tube substrate and the bottom of the corrosion pit was analyzed. The content of Cu in the matrix was 69.30%, and the content of Zn was 28.73%, which was consistent with the composition of HSn70-1A. At the bottom of the corrosion pit, the content of Zn was only 5.39%. It is much lower than the standard content of the HSn70-1A alloy, indicating an obvious dezincification of the corrosion site. Under the scanning electron microscope, white granular corrosion was observed on the outer surface of the bottom of the corrosion pit, and its elemental composition was mainly C, O and Ca. Therefore, according to the above analysis, it is believed that the corrosion of the brass tube of the thermal power plant is mainly pitting corrosion and dezincification corrosion occurring under the dirt. The reason for the pitting is CaCO₃ contamination in the brass tube, which causes the oxygen concentration difference between the metal and precipitation forming a battery. That is, the deposition of dirt on the surface of the brass tube causes a difference in the contact environment of the brass tube surface, thereby generating a certain potential difference. It is very difficult to obtain oxygen in the metal below the scale, and thus it is an oxygen-poor region-anode without scaling. The oxygen supply to the metal surface is sufficient for the oxygen-rich zone - the cathode. The large cathode and the small anode constitute an oxygen concentration battery, which causes pitting corrosion on the surface of the brass tube, which leads to accumulation of dirt and local corrosion, successively causes the brass tube to be perforated and destroyed in a short period of time. The generation of dirt is mainly related to the quality of the cycle. In the circulating water system in which calcium carbonate is supersaturated, the tendency of fouling to deposit is large, and the effect of concentration and temperature rise of impurities in the system increases the cohesive force of the particles. Especially in the supersaturated state of calcium carbonate in the system, the suspended particles in the water become seed crystals, forming the crystal of CaCO₃, then CaCO₃ and the suspended solids in water are co-precipitated on the surface of the brass tube, which is easy to form dirt. Further factors affecting fouling deposition include the flow state of the water, such as the flow rate, the turbulence or laminarity, and also the temperature of the tube wall. Generally, the solubility of calcium carbonate decreases with increasing temperature, and the higher the wall temperature, the greater the tendency of scale to crystallize.

The dezincification corrosion mainly dissolves the active zinc in the alloy through an electrochemical process. It is generally classified into layered dezincification and bolt-like dezincification. Layered dezincification is also known as uniform dezincification, in which case the zinc on the surface of the brass is stripped. When lamellar dezincification occurs in brass, the surface layer becomes the copper layer with decreased mechanical strength due to the dissolution of the active component zinc, and when it is subjected to water pressure or external stress, cracking will occur and the copper tube will be damaged. Brass with high zinc content can exhibit this form of corrosion in low-hard, low-pH still water, and is exacerbated by the presence of chloride and sulfate ions. The difference in oxygen under the deposition product of the gas-filled battery also promotes this corrosion. The bolt-like dezincification is also called local dezincification. Since zinc is more active than brass, the pores are formed on the local surface of the brass due to the dissolution of zinc, and the pores are sometimes covered by corrosion products. When the brass is corked, the corrosion product is a brittle,
porous brass residue that can remain in place or be washed away by water to cause perforation of the material. The etched holes generated by such local corrosion often have a significant depth along the direction of the vertical metal surface. Combined with the macroscopic morphology, it can be seen that the leakage of the brass tube of the condenser is a bolt-like dezincification corrosion.

In general, there are two mechanisms for dezincification of brass:\[12\]: one is the electrochemical mechanism of dissolution and redeposition. It is believed that the brass and zinc in the surface of the brass are dissolved in the anode of the micro-battery, and the zinc in the electrode potential loses electrons and becomes $\text{Zn}^{2+}$, remains in the solution; the brass in the electrode potential was first oxidized to $\text{Cu}^{2+}$, and then $\text{Cu}^{2+}$, the electrons are reduced and deposited at the cathode of the micro-battery to form a loose brass layer. The second mechanism is to preferentially dissolve the seepage diffusion mechanism. It is believed that the zinc in the brass surface layer is preferentially dissolved, and then the internal zinc continues to be dissolved through the seepage channel and the vacancy diffusion, then the brass is left behind to form a loose brass scale layer.

In both mechanisms, the overall reaction is the same\[6\], ie:

$$\text{Zn}=\text{Zn}^{2+}+2e^- \quad \text{(Anode reaction)}$$

$$\frac{1}{2}\text{O}_2+\text{H}_2\text{O}+2e^-=2\text{OH}^- \quad \text{(Cathodic reaction)}$$

4. Prevention of corrosion

Currently there are three methods of prevention and control, one is to use corrosion-resistant materials, such as stainless steel, titanium alloy, etc.; the other is to strengthen the rubber ball cleaning, the working principle is to squeeze the sponge ball larger than the inner diameter of the brass tube by means of the action of water flow, sponge balls go through the brass tube of the condenser, scrubbing the brass tube, therefore, effectively reduce the probability and degree of corrosion occurrence; the third one is the chemical cleaning technology, which dissolves and peels off the scale and its attachment by means of the cleaning agent. The descaling effect is achieved. Chemical cleaning requires different types of cleaning agents depending on the type of soil and the degree of fouling. Because this corrosion occurs when the brass tube protective film is destroyed or foreign matter is deposited, the deposition of these substances shields the oxygen, and the insufficient supply of oxygen causes the spontaneous repair of the spontaneously produced protective film to be continuously and effectively performed. The corrosion pit gradually develops under the sediment. Therefore, it is very important to strengthen the rubber ball cleaning when other methods cannot be taken to prevent leakage.

5. Conclusion

There are many corrosion pits in the inner wall of brass condenser tube, and the leakage of brass pipe was caused by the penetration of partial corrosion pit through the pipe wall. Through examination, the brass pipe substrate met the material requirements of HSn70-1A. The content of Zn was 28.73% in the matrix and at the bottom of the corrosion pit the content of Zn was only 5.39%. It was much lower than the standard content of the HSn70-1A alloy, indicating an obvious dezincification at the corrosion site. Combined with the macroscopic characteristics of corrosion pit, it can be concluded that the leakage mechanism of the brass tube of the condenser belongs to the bolt-like dezincification corrosion under the scale.

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