Failure analysis of a steam-water boiler

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Abstract. The explosion failure reason of a steam-water boiler was analyzed through macro analysis and theoretical calculation. The results show that the overpressure operation of the boiler is the main cause of the explosion accident.

1. Introduction
Steam-water boiler refers to the boiler which can produce low-pressure steam and high-temperature hot water at the same time. The boiler is widely used in hotels, restaurants, canteens and other enterprises. The causes of boiler explosion are generally divided into water shortage explosion and overpressure explosion. Boiler explosion accident usually causes great property loss and more casualties. Therefore, the systematic analysis of boiler explosion accident can provide necessary technical support for the safe operation of the boiler.

In the past, some boiler failures were analyzed. Abou-elazm et al. [1] studied the leakage failure reason of boiler secondary superheater tube. The results showed that the leakage was caused by stress corrosion cracking. Han et al. [2] studied and analyzed a series of fault phenomena of waste heat boiler in service. Srikanth et al. [3] analyzed the causes of corrosion failure of waste heat recovery boiler tubes. The results showed that the high corrosion tendency in low temperature section of boiler was directly related to the formation of hydrated ferric sulfate in these areas. Kishore et al. [4] analyzed the cause of acid dew point corrosion of economizer tube in coal-fired power plant. The results showed that the corrosion began to occur near the weld area and then propagated in multiple directions. Ding et al. [5] studied the root cause of tube shell side corrosion of economizer in HRSG. The results showed that the main reason of corrosion failure was sulfurous acid dew point corrosion caused by sulfur from methyl methacrylate waste liquid. Botha et al. [6] proposed a modeling method for fatigue failure of large boiler tube assemblies. The model was mainly used in the redesign of boiler parts, which can effectively reduce the fatigue failure. Firouzeh et al. [7] analyzed the failure reason of steam boiler tube in LPG treatment plant. The results showed that the formation of a large amount of scale on the steam side and the resulting thinning of the tube wall were the main reasons for the failure of the superheater tube.

In this paper, a explosion failure accident of steam-water boiler was analyzed. The cause of boiler explosion was determined.

2. Macroscopic morphology
The base of the failed boiler is shown in Fig. 1. It can be seen that the boiler base is relatively intact and in its original position. The boiler body has left the boiler base. There are no connecting parts or
welding marks between the boiler base and the boiler body. All the connecting pipes outside the boiler have been torn off and the roof of the boiler has been lifted off. A 1-inch galvanized iron pipe with a length of about 6 meters was found outside the boiler room and was confirmed as the water seal pipe of this boiler. One end of the water seal pipe is threaded and the other end is flat. The thread surface is deformed locally. The inner wall of the water sealed pipe is rust colored, and the zinc coating on the outer surface of the pipe is new and intact.

Figure 1. Boiler base.

The boiler proper was blasted to a warehouse about 200 meters away and lying horizontally in the warehouse. The macro morphology of the joint between the boiler proper and the bottom sealing plate is shown in Fig. 2. It can be seen that the part of the connecting weld between the lower part of the boiler liner and the bottom sealing plate is torn. The torn part is about 1/2 of the circumference. The boiler water pipe in the furnace was seriously deformed by the crushed furnace.

Figure 2. Macro morphology of the joint between the boiler proper and the bottom sealing plate.

The macro morphology of the joint between the boiler proper and the conical head is shown in Fig. 3. It can be seen that the connection between the boiler proper and the conical head is torn more than 1/4 of the circumference. The upper cone of the furnace is also severely deformed due to the collapse.
Figure 3. Macro morphology of the joint between the boiler proper and the conical head.

When the boiler falls, the top and bottom of the boiler were flattened due to the impact with the ground, as shown in Fig.2 and Fig. 4. The thickness of scale accumulated inside the boiler is about 1mm. There is much scale in the short connecting pipe of water seal pipe at the lower part of boiler body. The surface of external thread of pipe joint is very new and there is no trace of mechanical damage.

Figure 4. Macro morphology of the boiler head.

3. Results and Discussions

3.1. Calculation and analysis of the minimum pressure of boiler furnace collapse

It can be seen from the damage state of the boiler proper that the pressure in the boiler exceeds the external pressure that the furnace liner may bear, which leads to the instability of the furnace furnace and is crushed. The welding seam between the lower sealing plate and the furnace furnace and the connecting weld between the furnace furnace and the conical head are torn. Because the only water seal pipe connected with the atmosphere on the boiler is closed, it is not connected with the atmosphere. Therefore, the boiler operates in a fully closed state. With the increase of water temperature in the boiler, the volume of water in the boiler expands correspondingly, which eventually leads to the instability and fracture of the boiler furnace.

According to the standard GB/T 16508-1996 <strength calculation of pressure parts for shell boilers>, the calculation formula of minimum wall thickness required for vertical open hearth furnace is as follows:
Where, $t_{\text{min}}$ is the minimum required thickness, $p$ is the pressure, $D_n$ is the inner diameter of the furnace, $\varphi_{\text{min}}$ is the minimum attenuation coefficient, $\sigma_b$ is the tensile strength at room temperature, $L$ is the length. Assuming that there is no thinning of the boiler furnace at present, it can be obtained that when $p > 0.78\text{MPa}$, the boiler furnace will cause instability.

### 3.2. Analysis and calculation of boiler furnace collapse

The calculation formula of heat absorbed ($Q$) after fuel release is as follows:

$$Q = BQ_{\text{dw}}\eta t$$

Where, $B$ is the fuel consumption of the boiler, $Q_{\text{dw}}$ is the low calorific value of the fuel, $\eta$ is the thermal efficiency of the boiler, $t$ is the running time of the boiler. The fuel consumption of the boiler is 55kg/h. The boiler exploded after 35 minutes of operation. It is assumed that the low calorific value of fuel is 5000kcal/kg and the thermal efficiency of boiler is 70%, according to calculation, the heat absorbed by the boiler during this period is 112290kcal.

The formula for calculating the temperature at which water is heated is as follows:

$$T_2 = \frac{Q}{W} + T_1$$

Where, $T_2$ is the water heated temperature, $W$ is the weight of heated water, $T_1$ is the inlet water temperature of the boiler. The inlet water temperature of the boiler is 20℃, and the weight of the heated water is 1120kg. Therefore, the temperature of the water heated can be calculated as 120.26℃.

The relationship between temperature and pressure of hot water boiler is shown in Fig. 5. It can be seen from the figure that with the increase of boiler temperature, the relationship between boiler pressure and quadratic power increases. According to the equation of trend curve, the pressure of boiler may reach 2.25MPa at 120℃. According to the above calculation, the minimum pressure of furnace is only 0.78MPa. Therefore, when the boiler temperature reaches 120℃, the possibility of the boiler furnace being crushed exists.

![Figure 5. Relationship between temperature and pressure.](image)

### 4. Conclusion

When the accident occurred, the boiler was in full water state and all the valves above were closed. After the boiler was running, the water temperature rose. When the water temperature rose to 120℃, the expansion of water made the boiler pressure reach 2.25MPa, which led to the boiler furnace being crushed and the weld seam being torn.
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