Journal of Engineering Mechanics and Machinery (2023) DOI: 10.23977/jemm.2023.080102
Clausius Scientific Press, Canada ISSN 2371-9133 Vol. 8 Num. 1

# *The Analysis on the Causes of the Water Wall Pipe Burst in Industrial Boilers*

**Peng Xie[1], Lei Xu[2]**

[1]*School of Applied Chemistry and Materials, Zhuhai College of Science and Technology, Zhuhai, Guangdong, 519041, People's Republic of China*
[2]*"Shang Jingqing" Environmental Technology Co., Zhuhai, Guangdong, 519000, People's Republic of China*

***Keywords:*** Water wall, Pipe burst, Chemistry, Metallography

***Abstract:*** In view of the water wall pipe burst of the heating industrial boiler, the research group carried out the water vapor sample analysis, the incrustation scale analysis of the typical rupture test pieces and the metallographic analysis during the operation. The researchers studied the cause of boiler pipe explosion from the chemical and metallographic aspects of materials, and found that most of the damage forms were brittle explosion, and the metal surface protective film was completely or mostly dissolved and damaged, resulting in a wide range of water wall pipe damage. The macroscopic inspection of the appearance of the water wall pipes in the furnace and the measurement of the thickness of the water wall pipes should be carried out during the shutdown and maintenance period, and the pipe sections that have not met the safety requirements should be cut off. During boiler shutdown and maintenance, other water wall pipes at the same position were checked with a water-cooled wall pipe tester. This provides effective treatment measures to solve the water wall pipe burst of the boiler.

## 1. Introduction

Boiler water wall pipe burst and leakage is one of the common accidents in the boiler, which directly leads to the shutdown of the boiler, increases the maintenance cost, and brings great harm to the safe operation of production [1-3]. There are many factors that cause boiler water wall pipe explosion and leakage, among which high temperature corrosion is one of the main reasons. However, the harm caused by corrosion is a gradual process, which is not easy to cause people's attention. Therefore, it is necessary to analyze the causes of pipe burst and leakage of boiler water wall pipes in order to scientifically deal with possible accidents.

Based on the basic phenomena and laws of boiler corrosion and pipe burst, this subject studies the specific causes of pipe burst of boiler through the analysis of water and steam samples, the analysis of scale composition of typical pipe burst specimens and metallographic analysis, and provides a good idea for solving the pipe burst of industrial boiler.

## 2. Basic Phenomena of Boiler Corrosion

The high-temperature corrosion area of the water wall usually occurs near the centerline of the burner. The boiler with or without slagging may suffer from corrosion. Usually the front points on the fire-facing side of the pipe corrode the fastest [4]. Once high temperature corrosion occurs, the formation rate of protective oxide layer on the surface of water wall pipe is far less than that of high temperature corrosion. High temperature corrosion of water wall pipes generally has two appearance characteristics. One form of corrosion is that there is thick deposit on the outer wall, the appearance color is gray-white, the interior is layered structure, the outer layer is gray -white, and the lower layer is black deposits, which is denser than the outer structure. During mechanical peeling, the outer layer is granular and powdery, which is not firmly combined with the black deposit, and it is small, brittle and magnetic when separated. This kind of pipe has less corrosion. Another corrosion form is that there is a thin black deposit on the outer wall, with a thickness of about 0.5 mm. This form of corrosion is generally serious, loosely connected with the pipe wall, with a tendency of large pieces falling off by themselves, and hard texture. There is very thin black deposit on the pipe wall after separation, which is firmly connected with the pipe. Through the analysis, the two kinds of deposits have high sulfur content, most of which are mainly sulfides and less sulfates. In case of corrosion damage, the pipe wall layer is thinner, and the corrosion condition is speckled [5, 6]. This shows that during the operation of the boiler, due to the existence of sulfur and other harmful impurities in the coal, the water wall is corroded under high temperature. At the same time, a large amount of ash powder generated during coal combustion hit the water wall violently in the complex dynamic process of combustion inside the boiler, causing severe cutting on the water wall working face, causing the water wall pipe working face to be worn into small platforms of varying degrees, resulting in the actual thinning of the water wall thickness [7].

## 3. Test Methods and Results

### 3.1. Macro Inspection, Chemical Composition Analysis and Metallographic Analysis

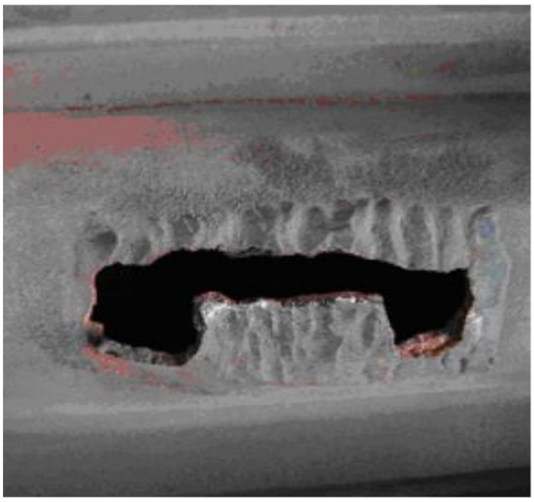

Figure 1: Appearance of window shaped bursting port.

Figure 2: Inner surface of pipe section near window shaped bursting port.

The research group selected two bursting ports in the representative failure pipe samples for research. Bursting port I: It is located near the weld crater of the water-cooled wall pipe, in a window shape, and cracks longitudinally along the pipe. The maximum longitudinal opening is 102.36mm, and the maximum transverse opening is 22.52mm. There is no obvious plastic deformation in the pipe section near the bursting port, and the edge is rough, showing brittle fracture morphology. The pipe wall is obviously thinner. The appearance of the bursting port is shown in Figure 1, and the inner surface state is shown in Figure 2.

Bursting port II: It is located near the elbow and presents crack-like burst along the longitudinal or transverse direction. There is no obvious plastic deformation in the pipe section near the bursting port. Oval corrosion products protruding from the inner surface can be seen on the inner wall of the bursting port, which is loose in texture. After removing the corrosion products, there are dish shaped corrosion pits on the inner surface of the pipe wall, with obvious corrosion thinning and corrosion under the scale. The appearance of the bursting port is shown in Figure 3, and the inner surface near the pipe section is shown in Figure 4. The morphology of pipe metal substrate after removal of corrosion products on inner surface is shown in Figure 5.

Figure 3: Appearance of crack-like bursting port.

Figure 4: Inner surface near the crack-like bursting port.

Figure 5: Morphology of pipe metal substrate after removal of corrosion products on inner surface.

### 3.2. Detection of Scale

#### 3.2.1. Macro Morphology of Scale

It can be seen that there is a thin layer of uniform reddish brown sediment on the inner surface of the pipe near the window shaped bursting port I, and the structure is relatively loose. Moreover, the deposits on the pipe wall at the fire facing side are obviously more than those at the back fire side, and dish shaped pits of different sizes can be seen after washing away the deposits.

Dense bulges with a diameter of 1mm to 5mm can be seen on the inner surface of the pipe section near the crack like explosion II. The color of the bulge surface is reddish brown, and the secondary layer is black powder. After peeling off part of the corrosion products, white salt concentrate can be seen. After pickling the corrosion products, there are dish shaped pits with different depths below the bulge. On the inner wall near the bursting port, there are discontinuous oval corrosion products protruding from the inner surface, with a length of 3-23.65mm and a thickness of 1-7mm. The texture is relatively loose, and the crack is located in the middle of the corrosion pit. After removing large corrosion products by mechanical method, silvery white metal matrix with small cracks, reddish brown corrosion products, black $Fe_3O_4$ and white salt deposit can be seen at the bottom of the corrosion pit. The depth of the corrosion pit can reach 3.1mm.

#### 3.2.2. Composition Analysis of Scale

The chemical composition of the sediments on the inner surface near the above two typical blast holes has been analyzed, and the results are shown in Table 1.

Table 1: Analysis results of corrosives and sediments.

| Sampling position | $Na_2O+K_2O$ | CaO | MgO | $Fe_2O_3$ | CuO | Scale content |
|---|---|---|---|---|---|---|
| A | 0.11% | 2.00% | 0.65% | 87.25% | 6.12% | 226.6g/m |
| B | 0.96% | 2.22% | 1.89% | 90.29% | 0.46% | / |

### 3.3. Material Analysis Results

Metallographic analysis has been carried out on bursting port I and II. It can be seen from the metallographic diagram near the bursting port I in Figure 6 that the metallographic structure of the material at the bursting port I consists of ferrite and a small amount of pearlite. A large number of intergranular cracks can be observed, and the pearlite near the crack is severely decarburized.

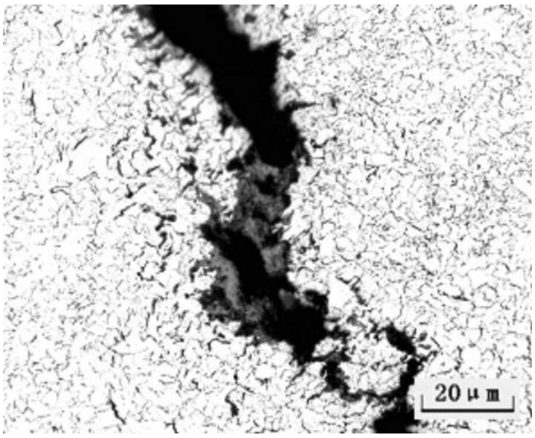


Figure 6: Metallographic diagram of bursting port I.

It can be seen from Figure 7 that there are a large number of black stripe microcracks in the metal matrix of the inner wall of the water wall near the bursting port II. The cracks are distributed along the grain boundary or exist at the interface between pearlite and ferrite. There are no corrosion products inside the crack. The scale layer is mostly separated from the matrix, and only a small amount is connected with the matrix. In Figure 8, the hydrogen embrittlement cracks in the matrix at a magnification of 600 times can be clearly seen in the metallographic diagram of the pipe etched with 4% nitric acid alcohol solution.

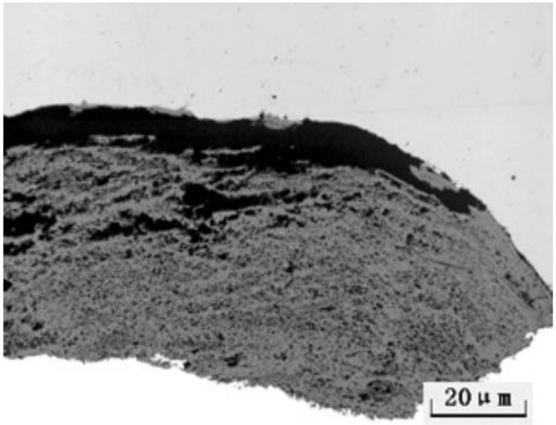


Figure 7: Metallographic diagram near the bursting port II (gray in the lower part: the scale layer, black in the middle: the gap, the uppermost part: the metal substrate).

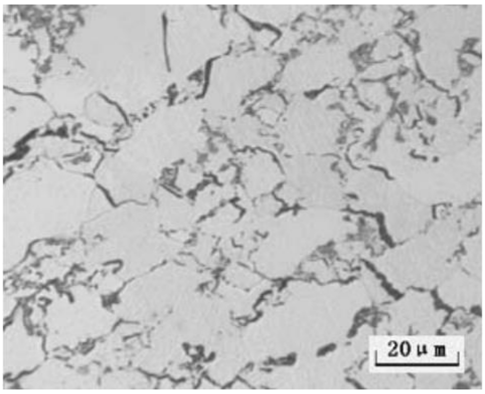

Figure 8 Metallographic diagram of bursting port II at 600 times magnification (etched by 4% nitric acid alcohol solution).

## 4. Discussion and Analysis

### 4.1. Failure Characteristics of Pipe Samples

According to the above experimental analysis results, the basic characteristics of water wall pipe burst are summarized as follows: a: There is no creep expansion and obvious plastic deformation near the bursting port, and the damage is brittle cracking. b: The scale layer structure on the inner surface of the pipe sample is composed of multiple layers, including iron corrosion products, oxides and salts. There is an obvious cavity between the scale layer and the metal substrate, and the metal substrate have the dish shaped corrosion pits after removing the scale layer. c: There are a lot of intergranular cracks and decarburization in the metal matrix under the scale.

### 4.2. Analysis of Pipe Burst Causes

From the macro inspection, chemical composition analysis and metallographic analysis of the above pipe samples, it can be seen that the pipe burst was caused by hydrogen embrittlement damage caused by acid corrosion under the scale. There are two sources of acid in the water vapor system. One cause: the overtemperature return water enters the ion exchange system, causing the ion exchange resin to be broken or thermally cracked. The resin micro powder enters the water vapor system, and the cation exchange resin sulfonic acid group produces strong acid in the environment of high temperature and high pressure. A small amount of strong acidic chemicals are brought into the water vapor system through the demineralized water system, and are cracked to produce organic acids. Another case: the corrosion products with high iron content will also reduce the pH of boiler water and cause acid corrosion.

The acidic boiler water has strong corrosivity and can dissolve the original $Fe_3O_4$ protective film of the water wall pipe, resulting in the following reactions.

$$Fe_3O_4+8H^+ \rightarrow Fe^{2+}+2Fe^{3+}+4H_2O$$

Once the iron surface is exposed to high-temperature furnace water, it is very vulnerable to corrosion:

$$Fe+NaH_2PO_4 \rightarrow NaFePO_4+2H^+$$

Corrosive boiler water enters the space between porous sediment and metal matrix in the inner pipe wall, and is concentrated. Corrosion occurs under the deposits. A small amount of salts in the boiler water, such as CaO, MgO, $Na_2O$ and $K_2O$, are concentrated and remain in the pores under the scale, forming corrosion products mainly composed of $Fe_2O_3$.

Atomic hydrogen will be generated in the process of corrosion of metal pipe wall by acidic medium, but it cannot be diffused into steam-water mixture in time. A large amount of atomic hydrogen is enriched between the metal pipe wall and corrosion scale. The hydrogen atom diffuses to the metal matrix, enters the metal grain boundary, and reacts with carbon or $Fe_3C$ as follows: $4H + C \rightarrow CH_4 \uparrow$, thus causing decarburization of pearlite. Due to the low diffusion coefficient of the generated methane, a large pressure is formed, which continuously accumulates between the grain boundaries, causing cracks to sprout on the grain boundaries, and continuously expand under the effect of stress. Therefore, a large number of intergranular cracks can be seen at the bursting port [8]. Due to the existence of intergranular cracks, the strength, toughness, plasticity and other properties of the metal are dramatically reduced, and hydrogen embrittlement explosion occurs under the effect of boiler medium stress.

## 5. Conclusion and Improvement Measures

When the boiler is subject to acid corrosion, the damage form is mostly brittle explosion, and all or most of the protective film on the metal surface is dissolved and damaged, causing extensive damage to the water wall pipes. This occurs in more than 30-50% of the total number of water wall pipe burst. As the surface facial mask is dissolved, the metal becomes active and must be treated to restore the passive state. For the water wall pipes that have undergone acid corrosion, the macroscopic inspection of the appearance of the water wall pipes in the furnace and the measurement of the thickness of the water wall pipes should be carried out during the shutdown and maintenance, and the pipe sections that have not met the safety requirements should be removed. After determining the cause of pipe burst, the water wall pipe tester shall be used to check other water wall pipes at the same position during boiler shutdown and maintenance. In conclusion, through chemical analysis and metallographic analysis, the failure causes of boiler water wall pipes are analyzed and discussed, and the conclusions are consistent. This also provides a new idea for us to discuss the failure causes of boiler metal materials.

## References

*[1] China Association of Boiler and Pressure Vessel Inspection. Industrial Boiler Inspection. Beijing: Industrial Science Press, 2009.*

*[2] Zhou G Q, Sun T. Industrial boiler safety technical manual (refined) Chemical Industry Press, 2009.*

*[3] Wang R, Wang Z, Wang X, et al. Pipe Burst Risk State Assessment and Classification Based on Water Hammer Analysis for Water Supply Networks. Journal of Water Resources Planning & Management, 2013, 140 (6): 04014005.1-4014005.8.*

*[4] Zhao Maiqun. Corrosion and Protection of Metals. Beijing: National Defense Industry Press, 2002: 71-88.*

*[5] Feng B, He T X, Zhang Y F. Study on high-temperature steam corrosion of the inner wall of superheater and reheater tubes. Hunan Electric Power, 2006, 26 (6): 8-11.*

*[6] Liu S W, Wang W Z. Failure analysis of the boiler water-wall tube. Case Studies in Engineering Failure Analysis, 2017, 9: 35-39.*

*[7] Jenkins C. Failure analysis: Vapor overheads discharge line for high level radioactive waste evaporator. Journal of Failure Analysis & Prevention, 2004, 4 (1): 33-36.*

*[8] Hu Q S, Zhou H C. Analysis of Pipe Burst Accident of Industrial Boiler. Energy Research and Management, 2013, 2: 95-98.*