Failure Analysis of the Furnace Scotch Boiler

Desiran Sembiring, Djoko Setyo Widodo, Bintang Adjiantoro, AB Saman, Bin ABD Kader

Abstract: Furnace Boiler is a part and parcel of a steaming kettle (boiler) of type Scotch, because forming condense very depend on size measure (wide of a hot surface) from Furnace Boiler, besides above the mentioned that maximum heat formed at the time combustion of fuel became the Furnace Boiler. To determine type and factors of a cause he happening of failure at a wall of Furnace Boiler from a steaming kettle of type of Scotch in factory taste this in the form of deformation of plastics at tabletop aiming to in till break. Type of examination performed within this research cover: visual perception, measurement of thick dimension of wall, fractography, metallography, hardness, tensile strength and analyze chemical composition of material Furnace Boiler and crust irrigate and also the hot simulation to material of Furnace Boiler.

The case of a failed Scotch boiler fire cylinder at this plant that broke. This failure can be categorized into the type of failure due to usage (service). Steam boiler fire cylinder is one of the most important parts in producing steam for the process. In the process of usage, a failure occurred in the form of a rupture. In this case the inner fire cylinder wall (the side of the fire) is directly related to the high temperature (flame core) which, by way of the beam (radiation), heat moves to the outer cylinder wall of the fire (the water side). This fire cylinder in its operating conditions receives pressure from outside in the form of water vapor pressure.Pursuant to above perception result, seen by that breaking Furnace Boiler because of some factor: The happening of corrosion at waterside Furnace Boiler surface which causing decrease thick at the cylinder wall. So that, this area corrosion unable to again accept pressure work boiler and happen by overheating causing substance mechanic denaturing, so that happened by the permanent deformation (plastic deformation).

Keywords: furnace, failure, plastic deformation, overheat, corrosion.

I. INTRODUCTION

Study of component failure is an activity or effort to investigate the causes of failure of a component. In this case it uses the term failure and not damage, because component failure is improper damage or damage occurs before the specified time/limit (age). While damage is a condition that can be categorized as reasonable because it has expired its useful life.

Component failure can occur other during use (operation) can also occur during manufacturing, storage or transportation. Besides that it can occur during design and is a very fatal component failure, for example an error in:

- Material Selection
- Determination of Burden
- Designing The Process / Fabrication Process
- Determination of Operating Conditions
- Environment and Others.

The failure of a component or part of the equipment while it is functioning can result in unexpected things. As a result of a failure, it is not only associated with risks to the safety of the human soul, but also to economic aspects. Economic aspects include not only operating costs and replacement of components, but also related to the decrease in the number of production (termination outside the schedule).

As in the case of the failure of the Furnace Scotch type boiler in this factory that broke. This failure can be categorized into the type of failure due to service. Steam boiler is one of the most important parts in producing steam for the process. In the process of ongoing use there is a failure in the form of rupture. In this case the inner furnace wall of the fire (fireside) is directly related to the high temperature (fire core) which with the emission (radiation), heat moves to the outer furnace wall of the fire (water side). This furnace in its operating condition receives external pressure in the form of water steam pressure.

From the results of observations the characteristics of failure are as follows; on the lip around the ruptured wall of the furnace there is thinning of the local thickness, the wall of the furnace is ruptured due to the tangential stress and there is water crust on the outer furnace wall of the fire (water side). From the results of the furnace failure evaluation caused by the occurrence of overheating due to the scale of the water that settles (*deposit*) so that it will inhibit the heat transfer process.

After a visual observation is carried out coupled with data information obtained from the boiler operator, the possible causes of failure on the boiler furnace wall are as follows:

Conditions for Scotch Boiler Operation

Year of Use	: 1990
Type	: Fire Tube
Capacity	: 5 ton steam/hour
Blow-down Ratio	: 5% toward water flow rate (10 – 15% Based on CL content)
Total solid of expected max	: 3.000 ppm
Total solid real	: 3.200 ppm
Steam Temperature coming out	: ± 179,9° C
Steam pressure coming out	: 10 kg/cm²
Temperature of furnace	: ± 750° C
Burner Fuel	: Diesel Oil (containing sulfur)
Operation time	: 24 hour/day for 2 years continually

Figure 1 and 2, Sketch of furnace position in Scotch Boiler

Revised Manuscript Received on October 15, 2019
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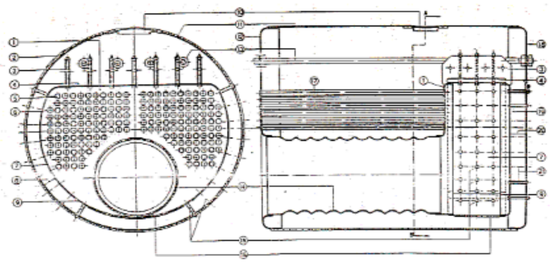


Figure 1. Scotch Boiler with One urnace

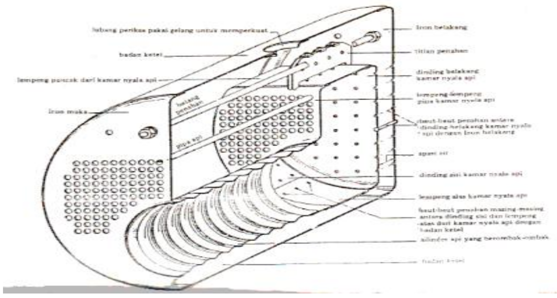


Figure 2. **The long display of oblique projection Scotch boiler**

II. Furnace Boiler Material Specification Data:

Material: H. II
Standard: DIN 17155, EN. 10029 / A
The dimensions of the furnace fire: D_{IN}. = 1000 mm, L = 2950 mm, t = 12.5 mm
Furnace shape: wavy (corrugated)
Furnace type: "Morison"
Weight = 3456 ponds**Testing**

After the process of cutting the furnace in the position just above the filling water, the damage is continued, then proceed to the next stage, namely testing. Tests carried out include a visual examination of ruptured areas, thickness measurement of furnace plate, macrographic examination, microstructure inspection, hardness testing, chemical composition analysis of furnace materials, scanning electron microscopy (SEM) examination, and corrosion product composition test by method energy dispersive spectroscopy (EDS).

Visual examination is carried out to identify the location of the furnace damage, the shape of the damage, and to determine the initial area of damage that will be selected for a more in-depth examination. This method is done by examining the condition and contours of the damaged area accurately and then documented with a digital camera.

Along with a visual inspection, the macrographic examination uses a stereomicroscope to identify the initial damage on the surface of the area to leak or ruptured so that the area can be exposed at a higher magnification than the visual inspection, so that clearer information can be obtained from the results of the macrographic examination. A macrographic examination is carried out with a magnification of 12x. Macrographic examination refers to the ASTM E 340-00 standard.

Metallographic examination using an optical microscope is performed to examine the initial damaged in more detail and around the damaged area associated with the microstructure and its changes during the operation process. In addition, metallographic checks are carried out to check for possible microvoid, micro-cracks, or other micro defects that may exist and influence the cause of damage and leakage of the pipe. The results were then documented with digital cameras. Metallographic test material preparation refers to the ASTM E 3-01 standard which includes several stages including:

1. Cutting metallographic specimens in the form of a cylindrical fire material/furnace using hand grinding
2. The process of forming / printing test samples using technovit or acryfix powder mixed with hardener liquid with a certain ratio, where the mixture of the liquid becomes hard it takes ± 1 hour.
3. The grinding/grinding process uses Struers hand grinding machines and silicon carbide (SiC) paper with various roughness, namely a combination of 80,120, 220, 360, 500, 600, 800, 1000, and 1200 mesh.
4. The washing process using 95% alcohol is then dried with a dryer (hairdryer).
5. The polishing process of the pipe test sample utilizes a diamond paste form.6. The micro-furnace plate test sample is then carried out, which refers to the ASTM E 407-01 standard where the solution used is Nital 2%.

Testing the hardness of the furnace boiler is carried out around the damaged area to determine the possibility of changes in the value of hardness that might cause damage or to find evidence of hardening due to quenching or otherwise softening due to annealing). The method used is the Vickers microhardness indentation method referring to ASTM E 92. The load used is 5 kgf using a diamond indenter. The Vickers method uses a tool called Vickers microhardness tester and the results obtained are measured by microscopy and calculated using the Vickers Hardness Number (VHN) hardness table. Chemical composition analysis of furnace boiler using optical emission spectrometry (OES). The examination is done to find out the type of alloy steel making it easier to choose replacement materials.(comparing the chemical composition of basic materials to standard pipe material, namely ASTM A 192.) In addition, testing is also used to evaluate the possibility of material degradation. Chemical composition checks refer to the ASTM E 415-99a standard.

Preparation of chemical composition test samples on pipe material by grinding and sanding with a roughness of 40 CCW.

SEM analysis is carried out on the surface of the damaged area to check the leakage form in more detail and to find other evidence that may exist and play a role at the beginning of the damage.

Corrosion product analysis uses the energy dispersive spectroscopy (EDS) method to check for suspicious elements such as aggressive ions or corrosive ions that might play a role in further damage.

The method of testing and examining the furnace boiler in the expanded position can clearly be seen in the flow diagram shown in the examination and testing of the damaged furnace plate.

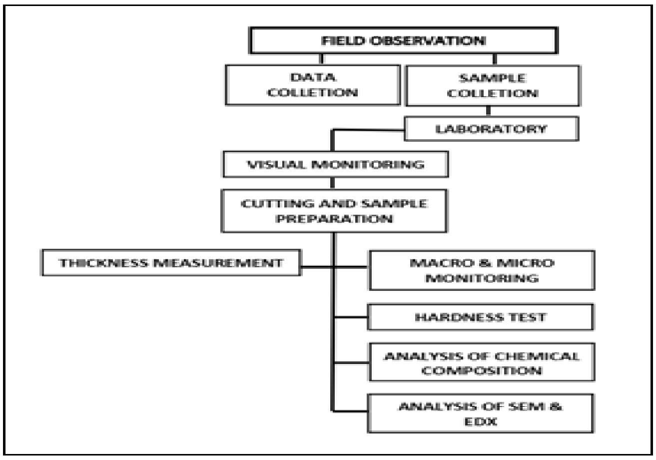


Figure 3. Flowsheet

III. Test Results

A. Visual and Macrographic Examination

Visually inspect the exact position of entry of boiler fill water and macrograph on the surface of the furnace of Scotch boiler in the right position of the water filler shows a rupture of 20cm (Figure 5).

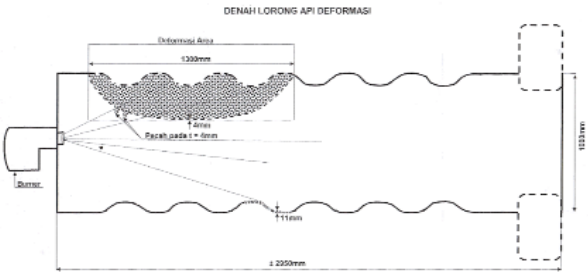


Figure 4. Position of the cross-section of furnace that has been damaged

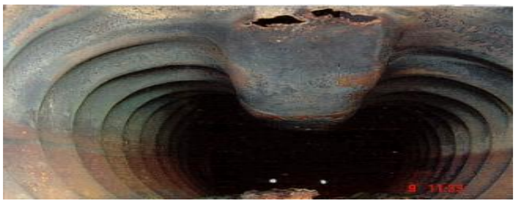


Figure 5.

The furnace wall which is bumpy at the top occurs plastic and ruptured deformation. Right at the diameter limit upwards which is blue, indicating identification at high temperatures.

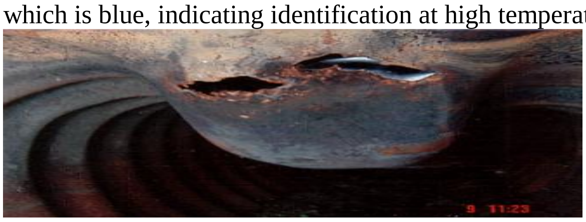


Figure 6.

A furnace is ruptured, so that the water steam pressure and water emanating from this hole precisely leads to the burner's mouth.

The rupture is indicated by the pressure/force of very high water steam which is sufficient to transform the cylindrical waves and push inward until the furnace experiences bulging in areas that have decreased strength due to high concentrations of heat (> the temperature of the annealing material) resulting in sufficient plastic deformation high.

Visual and fractographic examinations on the surface of a ruptured furnace are shown (Figures 7 to 10).

Figure 7. Fractography of a piece of a furnace at the upper fireside (side view)

Figure 8. Fractography of a piece of a furnace at the upper fireside (front view)

Figure 9. Furnace - the upper waterside that has failed, shows a change in shape (plastic deformation). A, B and C are the test sample areas.

Figure 10. Fractography of the furnace wall - the upper waterside at Location A

Figure 11. Fractography of a furnace - the upper waterside at Location B

Figure 12. Fractography of the furnace - the bottom fireside that is not subjected to plastic deformation.

B. Examination of Microstructure

Examination of the microstructure carried out on the furnace shows the presence of creeping cracks (Figure 13). Cracks propagating in the form of cracks at the grain boundary (intergranular) which contain corrosion products which are indicated to originate from fuel dust (Figure 14). Corrosion products are reinforced by evidence of the EDS analysis results in Table 6.

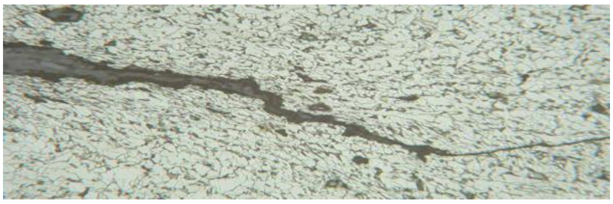


Figure 13. Microstructure in the fracture area which has a ferrite-pearlite phase. 500x

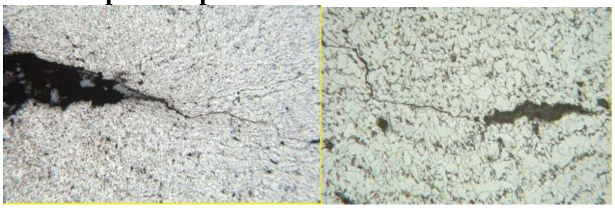
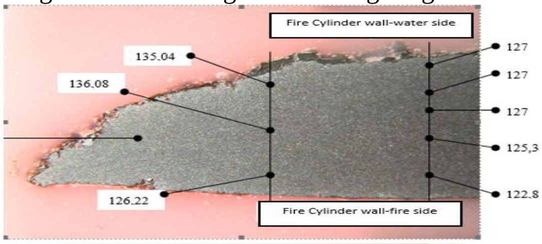


Figure 14. The microstructure of crack tip that occurs on the furnace wall, showing intergranular cracks of 200x Etch: Nital 2%.

In general, the furnace microstructure of ruptured fire consists of ferrite (bright areas) and pearlite (dark areas) which can be seen in Figure 13 and Figure 14 respectively.

Testing the hardness of the ruptured furnace is carried out to determine the change in hardness. From the results of the hardness test in both samples, it showed that the average hardness value of the ruptured furnace material was 136 VHN and 122 VHN, respectively. Data from the results of hardness testing are shown in Figure 15 through Figure 17.



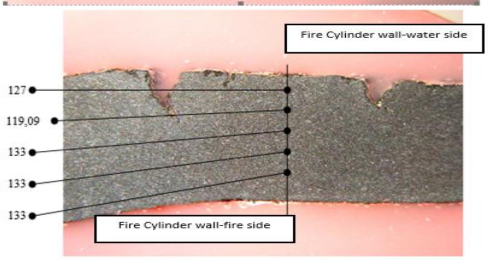


Figure 15. The deformed hardness of the furnace wall forming bulging and ruptured (sample pieces A)

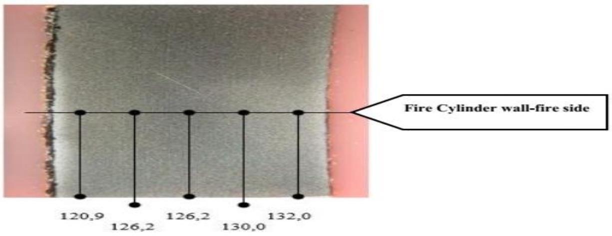


Figure 16. The hardness of the furnace wall closer to the occurrence of deformation (cut of sample B)

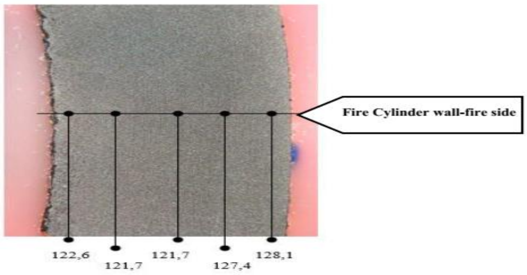


Figure 17. The deformed hardness of the furnace wall forming a curve (cut of sample C)

Table 1. Chemical composition of furnace material (in %)

	Furnace	DIN17155 H II
C	0,173	0,2
Mn	0,753	0,5 – 1,4
Si	0,275	0,4
S	0,006	0,025
P	0,009	0,030
Cu	0,009	0,30
Cr	0,018	0,30
Ni	0,0143	0,30
Al	0,0224	0,02
V	0,0003	0,02
Nb	0,0015	0,01
Ti	0,0025	0,03
Mo	0,0019	0,08

Table 2. Classification of furnace material

Condition	Tensile Strength Mpa	Yield Strength Mpa	Elongation %
Fire cylinder deformed plastically	319.77	433.58	40
Fire cylinder undeformed plastically	324.07	428.61	30
Standards DIN17155 H II	410/530	266	

Table 3. Condition Data for used water boiler

Parameter	Water Softener Inlet Water Boiler	Outlet Water Boiler	Back wash/14 Days
PH	6,77	11,08	11,49
Carbonat	40	740	600
TDS	45	0	1
Cl	3,5	405	643

C. Measuring Thickness of Furnace Boiler

Thickness at location Bulging (Bulging Area)
Nominal thickness = 12.5 mm
The maximum thickness of measurement is 11.9 mm
Minimum measurement thickness = 5.2 mm
Thickness in Normal location (Not Bulging Area)
Normal thickness = 12.5 mm
The maximum thickness of measurement is 12.5 mm
Minimum measurement thickness = 11.3 mm

D. Analysis of Chemical Composition

The results of testing the chemical composition of furnace material can be seen in Table 1. The tensile strength test results show that the furnace material is not in accordance with the standard material DIN 17155 H II, see Table 2. Furnace material when compared with the standard DIN17155 H II, then after being used as a material for furnace, the decreasing tensile strength tends to be softer, this can be seen from the value of the pulverization strength and percent elongation. Which is increasing.

E. SEM Analysis

The results of examination with SEM and EDS on the surface of the furnace in a ruptured position, can be seen in Figure 18 and Table 6.

Appearance on the surface of waterside of the furnace is a corrosion product in the form of a deposit. In the furnace the leaky side of the fire leaked detected elements such as carbon (C), silicon (Si), sulfur (S), potassium (K), and calcium (Ca) indicated by fuel.

Figure 18. SEM surface micrography of the deposit on the waterside of the furnace that has ruptured

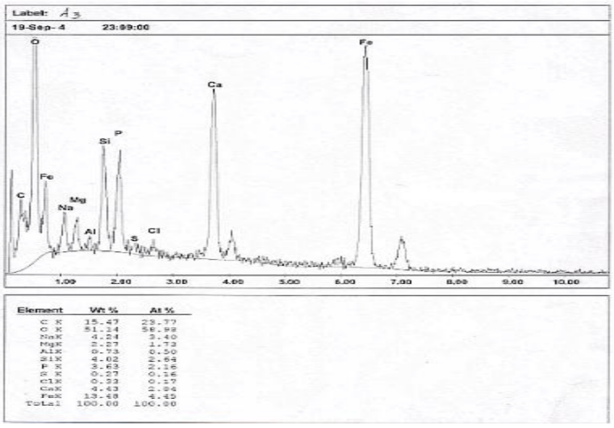


Figure 19. Analysis of the composition of the SEM-EDS deposit on the waterside of the furnace wall that has ruptured

Table 6. Analysis of the composition of SEM-EDAXS deposits on the waterside of the furnace wall that has ruptured.

Element	Wt %	At %
C K	15.47	23.77
O K	51.14	58.98
Na K	4.24	3.40
Mg K	2.27	1.37
Al K	0.73	0.50
Si K	4.02	2.64
P K	3.63	2.16
S K	0.27	0.16
Ca K	4.43	2.04
Fe K	13.48	4.49
Total	100.00	100.00

IV. DISCUSSION

In discussing the problem of steam boiler there are two aspects that must be reviewed, namely the problem of water and material of a boiler fire cylinder.

The boiler feedwater is usually from the condensate which is recycled. Feedwater must be processed first. Feedwater treatment includes decreasing hardness (hardness), reducing solids content, removing dissolved salts, fats and other organic compounds, removing dissolved air (oxygen), regulating pH and so on.

The boiler material must be in accordance with the conditions of its operation. Errors in the selection of furnace material cause easy attack by corrosion and mechanical strength decreases as a result of changes in grain structure.

In a survey at this company, it was found that the furnace wall of a boiler was bulging until it broke. With consideration of the above explanation and the results of observations, it is deemed necessary to measure the thickness of the wall of the minimum furnace, take water samples and the furnace fire material that is ruptured for research in the corrosion laboratory.

Based on the results of testing and observations made on the furnace wall of a boiler, below will be discussed the effect of operating temperature on phase changes and corrosion. Besides that, it also discussed the effect of water crust on corrosion on the furnace walls of a boiler.

A. Effect of Operating Temperature on Phase and Corrosion Changes on Steam Boiler Furnace.

As long as the steam boiler operates, the steam boiler furnace is heated and the pressure that comes from water pressure or water steam. If the furnace wall is unable to withstand the pressure, the furnace wall of the steam boiler will be ruptured. This event is very related to the operating temperature because the higher the wall strength of the furnace and the corrosion resistance will decrease.

From the observations of metallography on the ruptured and ruptured wall of the furnace, there was a phase change from ferrite + pearlite to a non-deformed (intact) furnace to ferrite and a little pearlite on the furnace which suffered plastic deformation (rupture).

Allegedly in the operational process, the furnace wall is overheating at around 600^{o}C (under austenite transformation) and relatively slow cooling so that the acicular ferrite grains resemble widmanstatten grains in the heat-affected (HAZ) area. In addition, pearlite degradation occurs due to long-term high-temperature conditions.

This is due to the formation of water crust on the furnace wall which can inhibit the heat transfer from the furnace wall to the boiler water. The water crust is a corrosion product that reacts with the cylinder wall of the fire, so the wall thickness will decrease and the furnace wall will overheat until the temperature is around 600oC. At this temperature the strength of the furnace wall will decrease. Because the furnace wall is not able to withstand the pressure from the water stream, the furnace wall of the fire will swell (bulging) and eventually ruptured.

Given that the high-temperature rise on the furnace wall of the fire is due to the presence of sufficiently thick water crust on the wall of the waterside furnace.

Apart from the description above, the metallographic observations on the fire-side of the furnace wall (figure 4.30a), indicate that the furnace wall has strong oxidation which is characterized by grain boundary corrosion attacks. This can reduce the strength of the furnace wall so that it will accelerate the damage.

B. Mechanism of Oxidation Reaction

The mechanism of the oxidation reaction above is as follows:

In the combustion chamber, which acts as an oxidizer, namely oxygen (combustion air), water steam and CO_2 gas from burning fuel oil.

$Fe + O_{2(g)} \leftrightarrow FeO/Fe_3O_4/Fe_2O_3$ ... ... 1)

$Fe + H_2O_{(g)} \leftrightarrow FeO + H_{2\,(g)}$... ... …… .. 2)

$Fe + CO_{2(g)} \leftrightarrow FeO + CO_{(g)}$ ……… ... .. 3)

Reaction (1) can occur when the combustion air is excessive. The oxidation limit of the boiler wall furnace material is 450^{o}C. In other words, the furnace wall material must be used to serve operations whose temperature does not exceed 450^{o}C so that corrosion and oxidation attacks can be avoided. But because of overheating, the oxidation and corrosion reactions can take place quickly. This means speeding up the damage to the furnace of a boiler.

C. Effect of Water Crust on Corrosion on Furnace of Steam Boilers.

The substances contained in large percentages in the crust include iron (13.48%), magnesium (2.27%) and sodium (4.24%) and chloride (0.33%). These last two elements can be corrosive to the steel furnace material of the steam boiler concerned.

The iron element is probably an accumulation of corrosion products from furnace fire materials or may come from feed water or source water.

High magnesium levels can be derived from feed water and can also be derived from the addition of MgO in the deposition process (external treatment) which it does not function properly and this is usually due to improper pH regulation.

Sodium or sodium can come from feed water, source water or from external and internal treatment processes. Elemental sodium in certain conditions is a dangerous element, among others, can carry out corrosion attacks which are known as Sodium Stress Corrosion or can cause decarburization (decarburizing) and so on to the steel of furnace of this steam boiler.

Chloride of 0.33% by weight (3300 ppm) can be a threat to steam boiler furnace, especially in cracks and crevices that may be present in the water-steam system in the boiler.

Regarding the contaminations mentioned above, further information is still needed on the results of an analysis of samples of source water, boiler feed water.

V. CONCLUSION

A. Rupture Causes of Furnace Boiler

The rupture of a furnace is caused by the wall of the waterside furnace experiencing an oxidation-reduction corrosion attack, with the reaction:

$(Fe^{+} \rightarrow Fe^{2+} + e,$

$2H_2O + 2e \rightarrow 2\,(OH) - + H_2$

so that there is thinning of the wall along with the thickening of the deposit which is on the water sidewall, this causes heat insulators or in other words heat transfer from the fireside of furnace wall to the waterside of the furnace wall is held by deposits of water.

The high one is somewhere (overheating) which results in:

- mechanical properties (ductility) change
- the furnace wall is not resistant to water steam pressure
- bulging occurs in the direction of the water steam pressure

Because the thickness of the wall of the furnace that has been corroded locally has been reduced (thinned) so that it is not strong enough to withstand water steam pressure and eventually rupture. From the various analyzes and observations that have been made, we can draw some conclusions and suggestions as follows:

1. Characteristics of furnace material are not in accordance with the DIN17155 H II standard. Furnace boiler is made of low carbon steel which has an oxidation limit or usage limit at a temperature of 450^{o}C.

2. Waterside of furnace boiler (just below the feed water) forms a layer of water crust (deposit) containing carbonate salts, such as $CaCO_3$ compounds.
3. The formation of a deposit or penetration of this surface will lead to pitting corrosion due to differences in anodic or cathodic reactions and so that the thickness of the furnace wall decreases.
4. Because the value of heat conductivity of $CaCO_3$ is relatively small (0.5-1) it will disrupt the heat transfer system and cause excessive local heat (hot spots).
5. At the minimum thickness of the furnace wall accompanied by a decrease in mechanical properties, the furnace wall is not strong enough to withstand water steam pressure so that it experiences excessive plastic deformation (bulging) and causes a ruptured in the area of a minimum thickness (5.2 mm).

B. Recommendations

Based on research data, it can be suggested that:

1. Periodically check the condition of the furnace boiler surface of the fireside of the water with visual inspection and NDT methods, measuring the thickness of the furnace wall, Engineering Replica (to see the condition of microstructure), measuring the hardness value (with Equotip Hardness Tester).
2. Perform mechanical cleaning or Chemical Cleaning that is suitable on the surface of the furnace boiler fireside water to be free from corrosion and scale products.
3. Avoid high temperatures which can improve softening (annealing during operation.
4. Placement of steam boiler feed water pipes needs to be considered again (in the form of a spray).
5. The combustion chamber temperature is maintained and does not exceed 450^{o}C, in accordance with the boiler design in question. Because of the higher the temperature the easier the formation of the crust during Calcium salt precipitation and avoiding soot (carbon) formed from the remnants of burning fuel.

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