JMES The International Journal of
Mechanical Engineering and Sciences
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Failure Analysis of Bend Tube Preheater on Heat Recovery Steam Generator

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Received:02 January 2017, Revised:01 February 2017, Accepted:03 March 2017

Abstract

The combined cycle power plant (PLTGU) is the second largest percentage of electrical production method which is 26% of all electrical production technology in Indonesia. One of the components in combined cycle power plant is heat recovery steam generator (HRSG), which serves as heat exchanger between hot gasses from gas turbine cycle and water from steam turbine cycle. There are four stages on HRSG, preheater, economizer, evaporator, and superheater. In the present work, there is a case of thinning on a bend tube preheater which exceed the tolerance limits, therefore the purposes of this research are determine the cause of failure and determine the failure mechanism on bend tube preheater. Thinning of bend tube preheater occurred due to corrosion from both the inside surface and outside surface. Corrosion that occurred on the inside surface of bend tube preheater caused by reaction between water and metal surface of tube. Corrosion on the outside surface could be happen caused by reaction between hot gas and metal surface of tube. Largest thinning rate occurred on bend area of bend tube preheater caused by deformation itself, it induces local reduction of breakdown potential.

Keywords: HRSG; Failure Analysis; Tube thinning; Corrosion

1. Introduction

Combined cycle power plant has both Rankine cycle by using steam turbine and Brayton cycle by using gas turbine. One of the components in combined cycle power plant is heat recovery steam generator (HRSG), which serves as heat exchanger between hot gasses from gas turbine cycle and water from steam turbine cycle. There are four stages on HRSG, preheater, economizer, evaporator, and superheater. Preheater serves as preliminary stage to heat water up to 50°C (Figure 1). Bend tube preheater use Grade ST37.8 from DIN 17177-79 standard as material specification with dimension specification can be seen on Figure 2. The initial thickness of bend tube preheater is 2.9 mm, where the critical thickness is 60% of initial thickness. After being used for 23 years (1992 - 2015) with standard working condition and operation, there is a case of thinning on bend tube preheater which exceed the tolerance limits and have to be replaced. Then, the purposes of this research are determining the cause of failure and determine the failure mechanism on bend tube preheater. Where each of specimen pipes have equal chemical composition taken as initial condition.

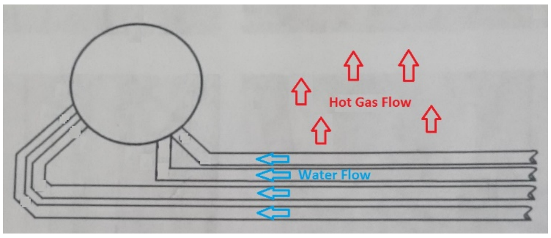

Figure 1. Water and hot gas flow direction on bend tube preheater

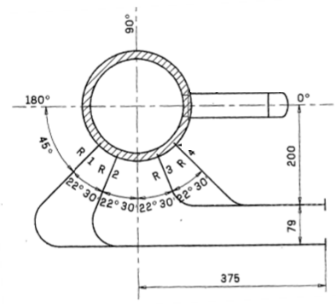

Figure 2. Bend tube preheater dimension specification

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2. Experimental Procedures

Research started with field observation to find out bend tube preheater location, working condition, and environment condition, and then we took maintenance schedule for bend tube preheater. After that, we did visual inspection on inner and outer surface of each specimens to find out any cracks or failure condition, and followed by 3D scanning. Then, we took samples from specimens by cutting them two-centimeter length and measuring each sample with 12 measuring points on front-side and 12 measuring points on back-side (Figure 3) to find out local thickness reduction rate. In the end, we did X-Ray Diffraction (XRD) test on inner and outer surface of bend tube preheater to get chemical compound of corrosion product, and also metallography test to saw corrosion product formed on pipe surface. We got 60 cutting samples form total 4 specimens, where divided by 15 samples from specimen 1A, 14 samples from specimen 1B, 15 samples from specimen 2A, and 16 samples from specimen 2B. From total 60 samples we got 1440 measuring points to locate local thinning rate on 3D images.

3. Results and Discussion

3.1. Bend Tube Preheater

Bend tube preheater uses DIN 17177-79 with ST 37.8 as a material grade, the material grade equivalent with ASTM A178 Grade A. Based on DIN standard, chemical composition of specimens stated in Table 1. Based on DIN 17177-79 standard, the material itself is belong to heat resistant low alloy steel which frequently used on heat exchanger tubes with low pressure condition, and so material is suitable to use as bend tube preheater. From field observation, we got bend tube preheater maintenance schedule, working condition and environment data stated in Table 2. Based on operational data history we conclude that specimens working condition within material limits.

Based on working condition and material specification we can find critical thickness of bend tube preheater with ASME B31.3. From ASME standard calculation, the critical thickness of bend tube preheater is 1.778 mm. So, the standard that company set for material rejection if exceeds 60% was suitable.

Table 1. Chemical composition and mechanical properties of the failed tube

Grade		St 37.8
Chemical Composition (%)	C	0,17 max
	Si	0,1 – 0,35
	Mn	0,4 – 0,8
	P	0,04 max
	S	0,04 max
Tensile Test (MPa)	Min Yield Point	235
	Tensile Strength	360 – 480
Elongation in 50 mm (%)		35

Table 2. Material and data operation

Information	Data
Material Type	Welded Boiler Tube (DIN 17177-79 ST 37.8)
Tensile Strength (MPa)	325
Using Period	23 years (1992 – 2015)
Outside Diameter (mm)	38
Thickness (mm)	2.9
Working Temperature Limit (oC)	180
Pressure Limit (bar)	5.4
Mass Flow Rate (ton/h)	1500
Pressure Limit High (bar)	75.5
Pressure Limit Low (bar)	5.4
Maintenance Schedule	Every 8000 Operating Hours

3.2. Visual Inspection

Visual inspection carried out on inner and outer surface of bend tube preheater was to find damage such as holes and cracks, forming of corrosion product, and color changes that occurs on the surface [1]. Visual inspection on inner surface of bend tube preheater showed that the entire surface covered with thin red-brick layer and distributed evenly along the surface pipe (Figure 4). It shows that corrosion processes associated with water as corrosive media occurred. There are not any visible damage such as cracks on the inner surface of bend tube preheater. So we concluded that the corrosion process occurred on the inner surface belong to the type of uniform corrosion[2]. On outer surface of bend tube preheater, there is a brownish-black layer that covered along surface pipe with even distributed (Figure 3). It shows that corrosion processes occurred on outer surface of bend tube preheater. There are not any visible damage such as cracks on the outer surface of bend tube preheater.

Figure 3. Outer surface condition of bend tube preheater

From the visual inspection on inner and outer surface of bend tube preheater, there are many indications that lead to thinning due to corrosion process. Therefore, it is necessary to doing measurement on each sample. First, each sample cut into two parts, thus forming into a cross-section A and B. Then we measured on 12 measuring points on front side of sample (marked with X1) and another 12 measuring points on the back side of sample (marked with X2), with a 10 mm distance of X1 and X2 as seen on Figure 4.

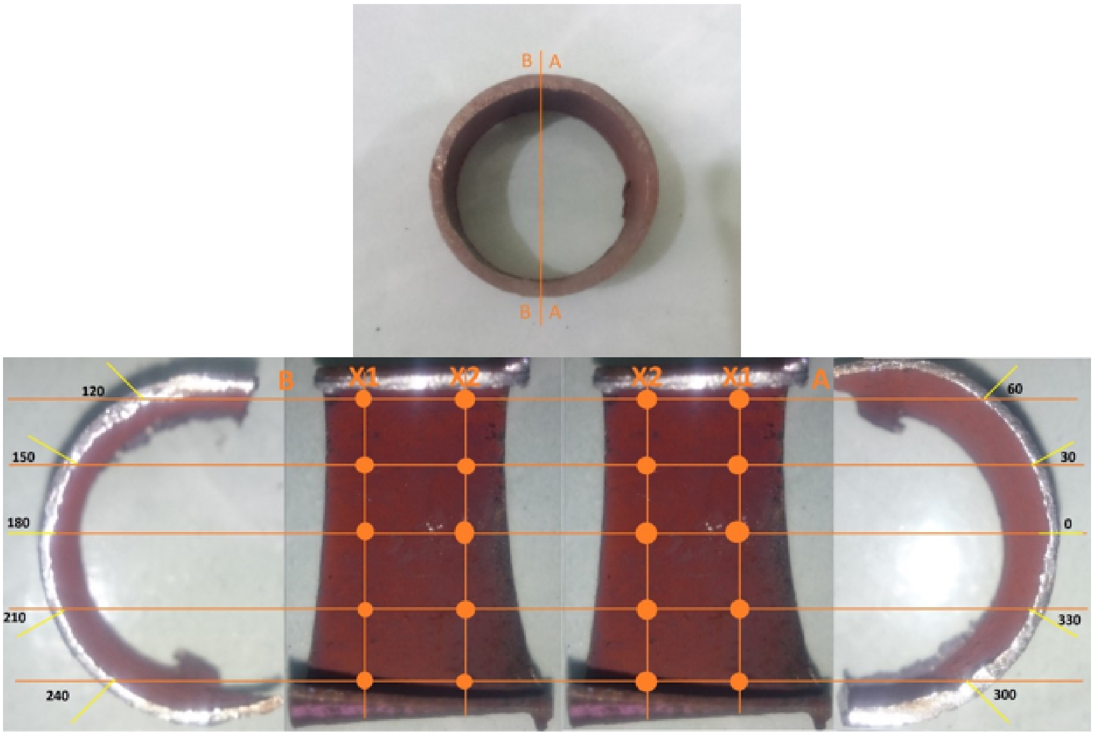


Figure 4. Measuring points on every sample

After measurement on each sample, the result of measurement is combined with 3D file of specimens from 3D scanning. Then, a codification was given to the combined 3D file to show the local thickness of pipes. The red color in 3D image shows if the location thickness is below the critical thickness (< 1.778 m), while the green color in 3D image shows the location thickness is still above the critical thickness (1.778 m). The combined 3D images results can be seen on Figure 5.

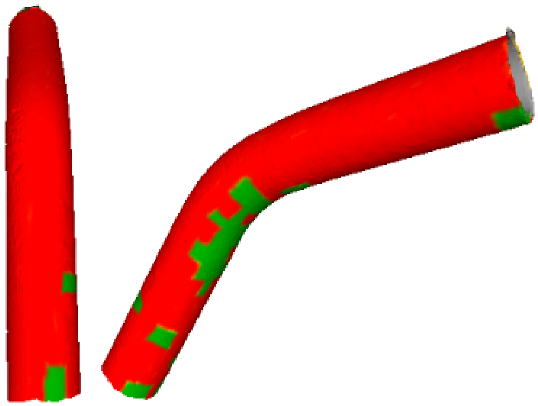


Figure 5. Combined 3D image for specimen 1B

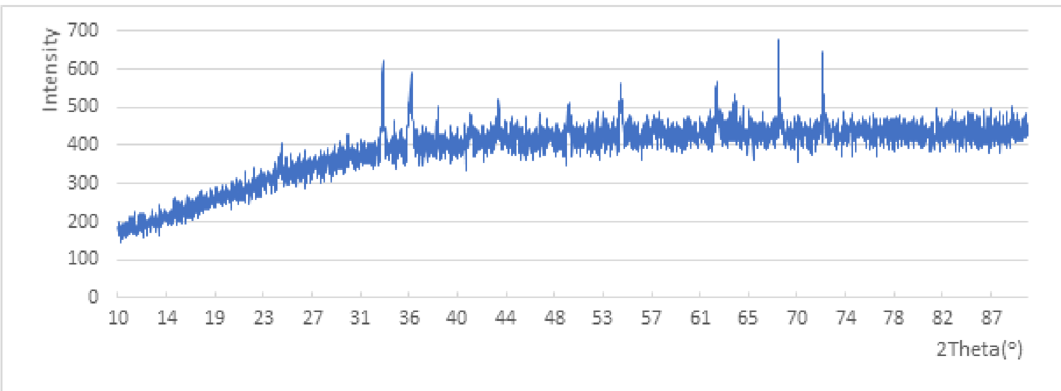
The result of visual inspection and measurement on inner and outer surface of each specimens showed that bend tube preheater is in critical condition and should be replaced, although there are not any signs of damaged such as leaking or crack on four specimens. However, corrosion process happens on every specimen based on color changes, reduction in thickness, and forming of oxide layer on specimen surface. Combined 3D image for other specimens can be seen on additional information chapter.

3.3. Corrosion Analysis

Pourbaix diagram explain forming of Fe_2O_3 as oxide layer causes the metal surface to be passive. A metal surface with Fe_2O_3 still undergo a corrosion process, but with a lower rate. But, the forming ofFe_2O_4 oxide layer causes the metal surface to be more passive or allow the metal to be resistant of corrosion. XRD or X-Ray Diffraction can be used to obtain chemical compound contained in corrosion product (rust). XRD test result will be used to perform advanced analysis related to corrosion process occurred on inner and outer surface of bend tube preheater. contaminants or abrasive particles, so the corrosion occurs in inner surface is pure due to direct contact between metal surface and water.

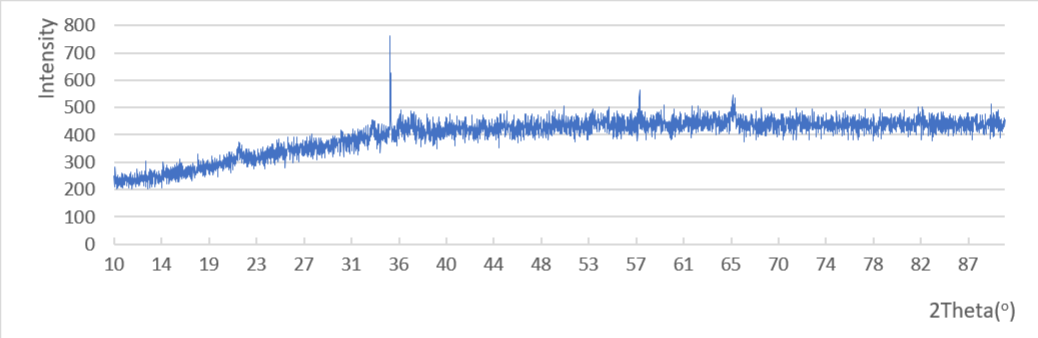
XRD test result on inner surface of bend tube preheater (Figure 6) showed, that red-brick layer is detected as hematite or Fe_2O_3. Hematite formed by direct contact between metal surface with water continuously. Hematite in inner surface of sample test formed with a thickness below 1 mm. Corrosion process occurs continuously due to the direct contact between metal surface and water, so that reduction of thickness also occurs continuously. From Figure 6 we also conclude that the inner surface of bend tube preheater undefiled from contaminants or abrasive particles, so the corrosion occurs in inner surface is pure due to direct contact between metal surface and water.

XRD test result on outer surface of bend tube preheater (Figure 7) showed, that brownish-black layer is detected as magnetite or Fe3O4 and sodium aluminum phosphate. Corrosion process that occurs on outer surface is different from inner surface due to the difference between corrosive media. A direct contact between metal surface and hot gasses from gas turbine combustion formed magnetite and chemical compound. The chemical compound can be different on every sample due to difference of contaminants in natural gas compound as gas turbine fuel and gas turbine working conditions. Magnetite in outer surface of sample test formed with a thickness below 1 mm.



Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	01-089-0597	54	Iron Oxide	0.139	0.796	Fe2 O3

Figure 6. XRD test result on inner surface of bend tube preheater



Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	01-075-1609	12	Iron Oxide	0.172	0.209	Fe3 O4
*	01-084-0198	24	Sodium Aluminum Phosphate	0.579	0.259	Na2.925 Al0.025 P O4

Figure 7. XRD test result from the outer surface of bend tube preheater

The bend-side of pipe is designed to flow the water from the preheater drum to economizer drum. However, the deformation of bend-side itself causes the pipe to be more susceptible locally to corrosion. The deformation on bend-side lower the breakdown potential locally, thus the bend-side of pipe more susceptible to corrosion rather than straight-side of pipe [3, 4, 5, 6].

Breakdown potential is electrical potential value on the surface of metals that is needed to determine the state of corrosion of the metal. By having smaller breakdown potential locally on bend-side, so that the area is easier to get into transpassive state and has greater corrosion rate. When the oxide layer breakdown, the surface is in direct contact with water. The potential difference occurs on the surface of specimen at bend-side area, causing pitting corrosion occurs. Where the surface of metal as anode and the metal oxide layer as cathode, so the thinning rate due to corrosion was greater at bend-side area.

The corrosion rate of a pipe can be determined by calculating the difference of the thickness at a certain of measured time interval. Corrosion rate can be formulated as the initial Thickness-Actual Thickness)/(Time Interval). By using the corrosion rate formula, we obtained local corrosion rate data on each sample. The highest corrosion rate occurs on specimen 1B sample 7 with 0.0956 mm/year. Sample 7 is located in bend-side of specimen 1B. After measuring the inside and outside diameter of each sample, we can obtain the comparison of largest thinning due to corrosion that occurred on inner and outer surface of bend tube preheater as stated in table 3. From Table 3, we know that the largest thinning due to corrosion occurred on the outer surface of bend tube preheater.

Microstructure analysis conducted to determine phenomena that occur on specimens due to working condition and environment. Material used in bend tube preheater is ST 37.8 with a maximum carbon content 0.17%. The outer surface of specimen contact with hot gases from the turbine gas combustion with a temperature up to 150° C and the inner surface contact with flowing water with a temperature up to 50°C. Sample that being used in microstructure test is sample number 1 from specimen 2A.

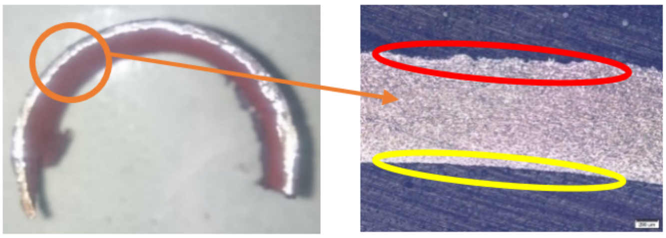
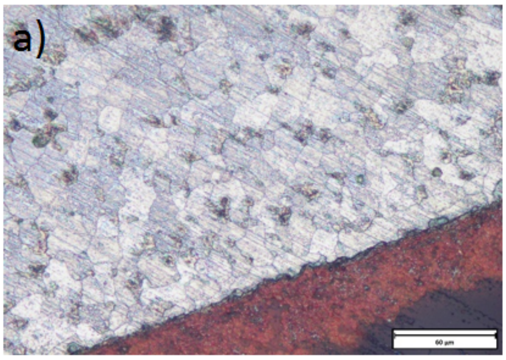


Figure 8. Microstructure analysis with 50x magnification

Microstructure test done with 3% Nital as etching reagent according to ASTM E407 [7]. The result of microstructure analysis with 50x magnification (Figure 8) showed a formed layer on inner and outer surface of bend tube preheater. The formation of red-brick hematite that occurred on inner surface of pipe marked by yellow circle on figure 8 with a thickness of about 7 micrometer or 0.007 millimeter. On the outer surface of pipe formed brownish-black that marked by red circle on figure 8 with a thickness of about 25 micrometer or 0.025 millimeter. With 50x magnification we can see oxide layer formed on inner and outer surface of bend tube preheater due to reaction of the specimens with working environment.

With 500x magnification on Figure 9a showed the establishment of hematite on inner surface with detailed image as marked with blue circle, there are not any indication that another oxide layer formed on inner surface. Figure 9b showed the establishment of magnetite on outer surface with detailed image as marked with green circle, there are not any indication that another oxide layer formed on outer surface. With 1000x magnification as seen on Figure 10, we can conclude that working condition and environment did not change any microstructural element of specimen. So we concluded that there are not any failure from working condition and operation. The result of microstructural test on sample is also suitable based on DIN 17177-79 chemical composition standard.



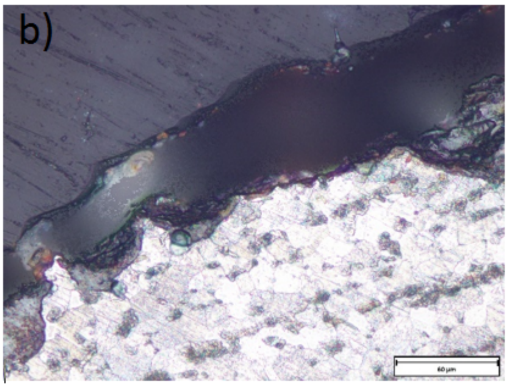


Figure 9. Microstructure analysis with 500x magnification (a) inner surface (b) outer surface of bend tube preheater

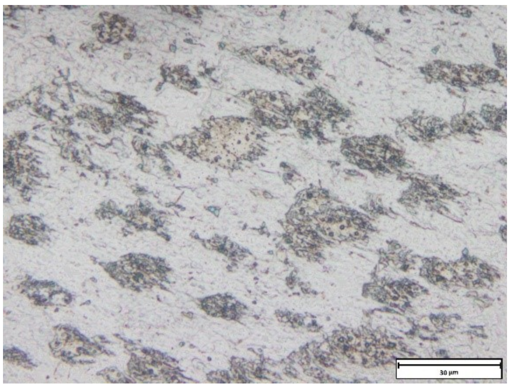


Figure 10. Microstructure analysis with 1000x magnification

4. Conclusion

Failure that occurs on bend tube preheater is not caused by heat recovery steam generator design and working operation, but due to the thinning of the pipe due to the corrosion process that are continuously occurred on the surface of bend tube preheater. However, the corrosion rate on each sample is different, but the largest thinning occurs at bend-side of bend tube preheater due to the deformation. The deformation caused a local decrease in the breakdown potential, the reduction of breakdown potential induces local corrosion process occur faster.

There is formation of oxide layer on inner and outer surface of bend tube preheater. Fe_2O_3 or hematite formed on the inner surface due to the reaction between metal surface of specimen and flowing water in bend tube preheater. Fe_3O_4 or magnetite formed on the outer surface of bend tube preheater due to the reaction between metal surface of specimen and hot gases from gas turbine combustion.

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