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Failure Analysis and Performance Assessment of Tubular Air Heater at PLTU South Sumatra V

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ABSTRACT

Tubular air heater has a design operational lifespan limit. This lifespan limit, if not monitored and controlled, can accelerate any damage. Tubular air heater damage will result in tube failures that affect the boiler heat transfer system and emission control. This research aims to find out the root cause of tube failure. This research analyses the physical failure mechanism related to the material: chemical composition test, hardness test, tensile test, metallography examination, SEM-EDX examination, and x-ray diffraction analysis. The failure mode analysis concluded that the tubes were attacked by sulphuric acid condensation due to the air heater tubes temperature drops below the sulphuric acid dew point temperature. The existing tubes material is Corten Steel, which has good atmospheric resistance but low in the acidic environment. One thousand two hundred tubes replaced with ND Steel, the ideal steel for sulphuric acid-resistant and 3,986 tubes used carbon steel. There is no air heater performance degradation after tubes replacement, indicated after two weeks outages at high load. The leakage significantly decreases from 64% to approximately 19%.

Keywords: *Tubular air heater, boiler, acid dew point*

1. INTRODUCTION

Air heaters are used to pre-heat the air before entering into a boiler furnace. Tubular air heaters are heat exchangers widely used in power plants, especially coal-fired steam power plant (CFSPP) with circulating fluidized bed (CFB) boiler type. It is used to increase the overall efficiency of the boiler. The water inside the boiler tubes converted into steam by coal combustion inside the furnace, thus producing a considerable amount of heat. The coal particles inside the furnace require the least temperature to ignite, and the stoichiometric-ally required air with appropriate intermixing [1]. To reduce the amount of coal energy that is flowed to heat the air so that the coal burns, air heaters are used to save the coal required to achieve the furnace's air temperature.

In a tubular air heater, cold air flows in the tube while hot flue gas passes through the tube. Many limitations are also associated with air heating. The failure that generally occurs is that the part of the tube surface exposed to the flue gas experiences corrosion. The reason is that the flue gas that comes out of the furnace is full of ash and dust particles [2].

Unit 1 air heater leakage percentage increased from 36.23% in March 2020 to 64.50% in June 2020. It affects the heat transfer; thus, air temperature decreased, and combustion in the boiler furnace became incomplete. The objective of this research is to find and investigate the failure analysis that occurred on the tubular air heater of unit 1 at PLTU South Sumatra V. It is needed in order to find out the troubleshooting and assess the performance of the tubular air heater.

2. MATERIALS AND METHOD

2.1. Visual Check

The investigation is started with a visual examination of the failed air heater tube sample. The tube is observed for physical appearance and the damage features.

2.2. Laboratory Test

The investigation is supported by some laboratory tests related to the material: chemical composition test, hardness test, tensile test, metallography examination, SEM-EDX examination, and x-ray diffraction analysis.

2.3. Tube Replacement

During the maintenance outage of Unit 1, the air heater's failed tubes would be replaced by good material that ideal for an acidic environment.

2.4. Performance Assessment

There are specific performance indicators to evaluate the performance of an air heater [3].

2.4.1. Air Heater Leakage

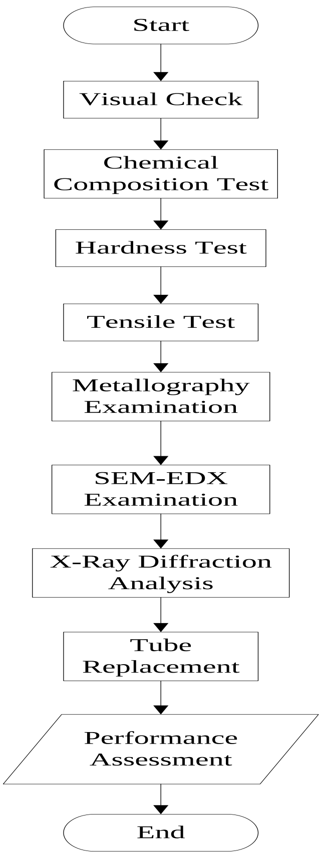
$$\%AHL=\left(\frac{O_{2\ outlet}-O_{2\ inlet}}{20.9-O_{2\ outlet}}\right)90 \quad (1)$$

2.4.2. Air Heater Efficiency

$$\eta_{ah} = \frac{T_{gi} - T_{gnl}}{T_{gi} - T_{ref}} \times 100\% \quad (2)$$

$$T_{gnl}=T_{gl}+\frac{\%AHL(T_{gl}-T_{ref})}{100\%} \quad (3)$$

2.5. Flowchart



3. RESULTS AND DISCUSSION

3.1. Failure Analysis

The material of air heater tubes has been investigated in the laboratory for the root cause of failure. The material check includes a visual check, chemical composition test, hardness test, tensile test, metallography examination, SEM-EDX examination, and x-ray diffraction analysis.

3.1.1. Visual Check

The failed air heater tube is observed on its external surface and corrosion products in different colours: red-brownie and yellow-white. The corrosion products with red-brownie colours are easily crumbled from the tube. Meanwhile, the corrosion products with yellow-white colour are not easily removed from the surface of the tube. The visual examination revealed that the tube had experienced thickness loss due to external corrosion. It is because corrosion products are mostly found on the external surface. The internal surface of the tube is found satisfactory with no signs of degradation.

3.1.2. Chemical Composition Test

The air heater tube material was subjected to chemical composition tests using Optical Emission Spectrometry (OES). The sample in Figure 1 was cut for a flat surface. Table 1 contains the chemical composition test result of the tested sample.

Figure 1 Failed air heater tube.

3.1.3. Hardness Test

The hardness test is conducted on a sample air heater tube using a Rockwell Hardness Tester Machine. The sample was cut for a flat surface. The hardness test results in comparison with Mill Certificate data are shown in Table 2.

Table 2. Result of air heater tube hardness test

Sample Code	Hardness HRB
Failed air heater tube	70
Q355GNH	n/a

The hardness of the tubes sample has been checked, and the results found that the hardness is typical for the type of carbon steel. It is not as hard as possibly caused by improper cold work or heat treatment.

Table 1. Result of air heater tube chemical composition test

Sample Code	C	Si	Mn	P	S	Cu	Cr	Ni	Fe
Failed air heater tube	0.07	0.33	0.47	0.083	0.008	0.27	0.53	0.07	Bal.
Q355GNH	Max 0.12	0.20-0.75	Max 1.00	0.07-0.15	Max 0.02	0.25-0.55	0.30-1.25	Max 0.65	

3.1.4. Tensile Test

The tensile test was conducted on the tube material using Universal Tensile Machine. The tensile test is performed on the tubes sample, and the results are shown in Table 3. It is found that the yield strength of a failed air heater tube cannot be determined, and its elongation is very much lower than the minimum requirement for corten steel (Q355GNH).

Table 3. Result of air heater tube tensile test

Sample Code	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)
Failed air heater tube	500	n/a	4.16
Q355GNH	490-630	345-355	Min 22

3.1.5. Metallography Examination

The Air heater tube was cut and prepared for metallographic examination. The preparation for metallographic examination includes mounting, grinding, polishing and etching. The etching was conducted by using a Nital solution to reveal the microstructure. The images in Figure 2 show the cross-section observation of the failed air heater tube. The specimen for metallography analysis is taken from the failed air heater tube, respectively. The macro photography shows that the tube is classified as an ERW tube as the long seam weld is observed on the cross-section.

The other image represents the microstructure of the failed air heater tube. The air heater tube's microstructure is identified as ferrite (white grains) and pearlite (dark grains). It is usual for low alloy carbon steel, whereas for the carbon content of 0.07% and 0.09%, the ferrite grains will dominate the microstructure. No cracks are found in the microstructure, and the corrosion process causes grains degradation. There is no abnormality in the microstructure of the failed air heater tube.

Figure 2 The microstructure of the failed air heater tube.

3.1.6. SEM-EDX Examination

A scanning electron microscope test was conducted on the fracture surface area of the failed air heater tube to observe the fracture's feature, as seen in Figure 3 and Figure 5. EDX test result on surface fracture is presented in Figure 4 and Figure 6.

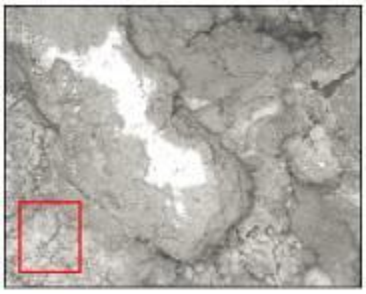


Figure 3 Fracture of red-brownie corrosion products.

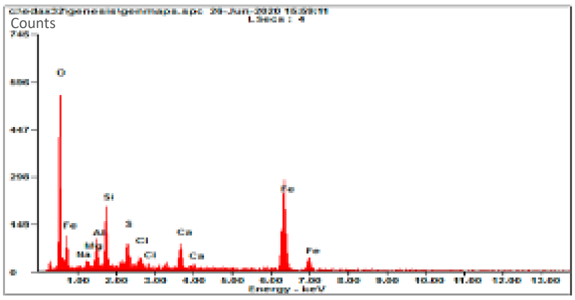


Figure 4 EDX test result of red-brownie corrosion products.

The EDX results analysis on the red-brownie and yellow-white corrosion products found the elements such as sodium (Na), magnesium (Mg), aluminium (Al), silicon (Si), sulphur (S), chloride (Cl), and calcium (Ca) came from the flue gas as results of coal combustion. The oxygen (O) came from the air while the iron came from carbon steel. From this analysis results, the corrosion products are predicted as iron oxides.

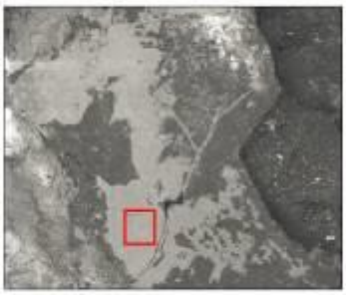


Figure 5 Fracture of yellow-white corrosion products.

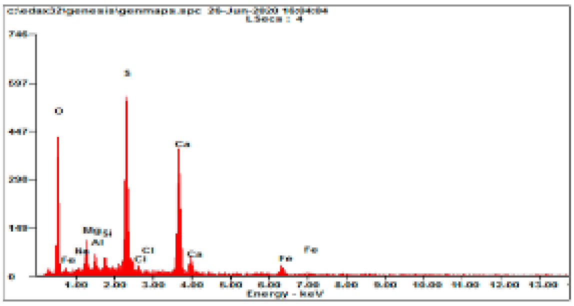


Figure 6 EDX test result of yellow-white corrosion products.

The heating process in the air heater is used to heat the combustion air using the heat from the flue gas that comes from the boiler furnace. The analysis of corrosion products using SEM-EDX found elements typically found in the flue gas resulted from coal combustion. However, the content of sulphur is measured very high compared to other elements. It can be very high because the corrosion products result from carbon steel reaction with sulphuric acid or hydrogen sulphide, which are the flue gas elements.

In the combustion of coal, the sulphur is oxidized to sulphur dioxide (SO_2), further oxidized to sulphur trioxide (SO_3). If the water vapour presents in the environment, it will react with sulphur trioxide (SO_3) to form vapour of sulphuric acid (H_2SO_4). The vapour of sulphuric acid (H_2SO_4) can condense into liquid sulphuric acid (H_2SO_4) if the temperature drops below the dew point of sulphuric acid (H_2SO_4) [4]. This liquid sulphuric acid (H_2SO_4) is detrimental to carbon steel as it will act as an electrolyte for wet corrosion to occur.

The corrosion products from the reaction of carbon steel with sulphuric acid can be distinguished visually as a yellow-white layer on the air heater tubes' surface. This type of corrosion is called low-temperature acid dew-point corrosion and frequently occurs in heat recovery systems such as air heaters of steam power plants [5]. Other consequences of the formation of liquid sulphuric acid (H_2SO_4) are that it attracts the ash deposition on the tube surface, creating another threat of corrosion, i.e., under-deposit corrosion. Tube plugging could also be caused by this deposition/fouling effect from the attracted ash.

3.1.7. X-Ray Diffraction Analysis

One of the outer surfaces of the tube has a crumbling corrosion product. The corrosion product was taken and mashed up into fine shape and analysed using X-ray Diffractometer. The purpose of this analysis is to identify the compounds in the corrosion products.

Table 4. Corrosion products compound

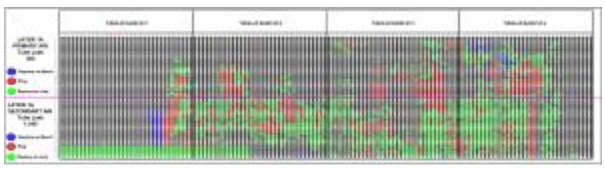
Ref. Code	Compound Name	Chemical Formula
00-002-0273	Goethite	α-FeOOH
01-073-0603	Hematite	Fe_2O_3
01-075-1609	Magnetite	Fe_3O_4
01-075-0600	Pyrrhotite	$Fe_{0.95}S_{1.05}$

The XRD analysis results of the corrosion products collected from the air heater tube's external surface are presented in Table 4. The compounds which are successfully identified in the corrosion products are Goethite (α-FeOOH), Hematite (Fe_2O_3), Magnetite (Fe_3O_4) and Pyrrhotite ($Fe_{0.95}S_{1.05}$). These compounds are the product of wet corrosion, where there must be an electrolyte on the external surface of the tube, which facilitates the electrochemical reaction for corrosion. The corrosion products as goethite, hematite, and magnetite are the product from carbon steel's reaction with oxygen in the electrolyte. Meanwhile, the corrosion product identified as pyrrhotite is the product from carbon steel's reaction with hydrogen sulphide (H_2S), which can be formed in an environment that rich in sulphur.

The tubes' surface is covered with iron oxide and ash deposits, which also react with the condensed sulphuric acid (H_2SO_4). The condensed acid can penetrate the layers and reacts with the metal surface. The compounds, i.e., FeS, Fe_2O_3 and Fe_3O_4, are confirmed after analysing the air heater tube's corrosion products using XRD. Therefore, it was confirmed that corrosion of the air heating tube's outer surface was caused by corrosion of the acid dew point temperature.

3.2. Tubes Replacement

In March 2020, 188 tubes were being replaced and 913 tubes being plugged. It got worse in July 2020. Two thousand one hundred twenty-one tubes were being replaced and 806 tubes being plugged at side A. While at side B, 3,065 tubes were being replaced and 107 tubes being plugged. One thousand two hundred of 5,186 tubes were used ND steel material, the ideal steel for sulphuric acid-resistant. Furthermore, the rest were used carbon steel type A106 SCH 40, which good on the acidic condition. The corten steel is weather resistance at atmospheric conditions but poor performance in the acidic environment. The mapping of air heater tubular replacement is shown in Figure 7.



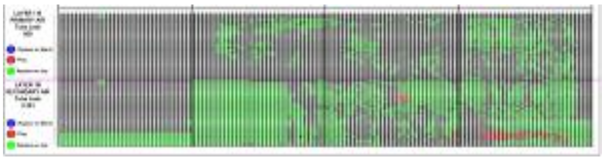


Figure 7 Unit 1 air heater tubes replacement mapping.

3.3. Performance Assessment

The air heater performance assessment results before and after tube replacements are shown in Table 5 below. It depicts the air heater performance increase after tubes replacement from 58% to 60%. The leakage significantly decreases from 64% to an average of 19%.

Table 5. Performance assessment result of the air heater tubes

.Parameter	Unit	Before Tubes Replacement			After Tubes Replacement		
		02/06/20	05/06/20	06/06/20	20/07/20	21/07/20	23/07/20
Load	MW	152.00	151.91	152.04	171.08	171.79	172.09
Total PA Flow	m^3/h	233839.01	229893.74	224796.93	244647.97	246770.24	251340.45
Total SA Flow	m^3/h	279741.68	277803.47	277619.84	338335.55	335041.17	330752.56
O2 in Furnace	%	1.84	1.71	1.30	2.35	2.18	2.47
O2 in Flue Gas	%	9.71	9.74	9.48	5.74	5.54	5.56
Air Heater A Outlet Temperature	^oC	100.46	98.47	100.78	128.88	130.73	129.89
Air Heater B Outlet Temperature	^oC	94.10	93.28	94.54	130.86	132.04	130.27
Temperature Corrected	%	138.62	137.25	139.96	129.87	131.39	130.08
Air Heater Leakage	%	63.32	64.78	64.43	20.13	19.65	18.19
Air Heater Efficiency	%	58.72	58.99	58.28	60.94	60.52	60.70

It can be seen in Figure 8 that the outlet temperature of air heater tubes drops below the acid dew point temperature compared with acid dew point temperature from references [5-7]. The consequence is the condensation of the sulphuric acid vapour on the surface of the air heater tubes. The outlet temperature increased after tube replacement.

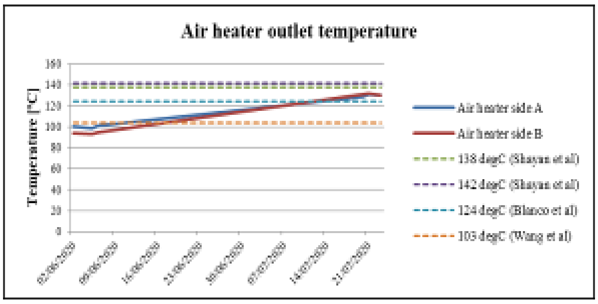


Figure 8 The air heater outlet temperature.

4. CONCLUSIONS

To identify the failed tubular air heater's failure analysis further investigated with several laboratory tests related to the material. It is concluded that the tubes were attacked by sulphuric acid condensation due to the air heater tubes temperature drops below the sulphuric acid dew point temperature. There were 1,200 tubes replaced from corten steel to ND steel material, which is the most ideal for sulphuric acid-resistant. Moreover, the rest were used carbon steel type A106 SCH 40, which good on the acidic condition. The outlet temperature increases after tube replacement, and the leakage significantly decreases from 64% to an average of 19%.

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