Syntax Literate: Jurnal Ilmiah Indonesia p–ISSN: 2541-0849
e-ISSN: 2548-1398
Vol. 9, No. 7, Juli 2024

CAUSE ANALYSIS AND IMPROVEMENT MEASURES FOR SUPERHEATED PLATEN TUBES FAILURE OF A 580 t/h CFB BOILER

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Abstract

One of the most frequent causes of coal fired power plant shutdown is boiler tube leak. Superheaters are crucial components of boilers operating under high temperatures and pressures. Understanding the superheater potential damages is essential to define the rectification action needed to keep and elevate overall power plant productivity. This paper highlights the analysis of platen superheater tube failure in a 2x150 MW coal-fired power plant in South Sumatera. Various test including chemical composition, hardness, tensile, metallography, SEM fracture surface examination, and XRD compound analysis were conducted for investigation purposed. The failure was initiated by the plugging of the tube elbow due to deposits and ashes adhering to the tube's interior. This obstruction prevented saturated steam flow inside the tube, leading to overheating and a subsequent drop in mechanical strength. Overheating was confirmed by the presence of spheroid particles in the ferrite matrix. Prolonged overheating resulted in the formation of microvoids, leading to creep failure and crack formation in the tube. The improvements made by adding refractory material give positive results. The platen superheater tubes which previously exceeded temperature limits, currently operate within normal range temperatures, reduced spray water consumption 6-10 tons/day, and significantly increased boiler efficiency from 83.19% to 83.54%.

Keywords: *coal fired power plant, platen superheater, tensile test, metallography analysis*

Introduction

Fossil-fuel power plants remain the primary electricity suppliers in Indonesia, with coal serving as the predominant fuel source. Among the crucial components of these power plants, the boiler plays a pivotal role. Boilers are tasked with generating superheated steam, which in turn powers steam turbines. Within the boiler framework, critical elements such as the economizer, water wall, superheater, and reheater are essential for efficient operation (Basu & Fraser, 2015). However, despite advancements in design engineering and material science, boiler tube failures continue to be a prevalent issue, leading to unscheduled outages and significant financial losses in thermal power plants (Lamping & Arrowood Jr, 1985). In the landscape of power generation, Circulating Fluidized Bed (CFB) Boilers are fundamental to Indonesia's industrial development. Yet, ensuring the reliability and safety of these systems remains paramount. The occurrence of forced shutdowns, primarily attributable to boiler-related issues, underscores the criticality of addressing and mitigating boiler tube failures (Munif, 2020; Widjajanto et al., 2024).

One such power plant, located in South Sumatera, operates a Circulating Fluidized Bed (CFB) boiler model DG 580/13.8-II1. In this paper, failure analysis of the

How to cite:	Chelsi, & Pamungkas, M. C. D. (2024). Cause Analysis and Improvement Measures for Superheated Platen Tubes Failure of a 580 t/h CFB Boiler. *Syntax Literate. (9)7.* http://dx.doi.org/10.36418/syntax-literate.v9i7
E-ISSN:	2548-1398

superheater tube is comprehensively investigated with guidance of previous research and literature study. The research is based on events of tube failure that occurred in 2017-2021. Consequently, plant downtime in July 2021 almost 2 weeks for recovery. The location of tube failures in platen superheater at 2x150 MW coal fired power plant shown in figure 1.

Figure 1. The location of the tube failure

The platen superheater, designed to raise the temperature of superheated steam from 392°C to 505°C, comprises eight membrane-type structures strategically positioned at the upper part of the furnace, adjacent to the furnace front wall. The tubes are made of 12Cr1MoVG material, intended for operation below 545°C (with a limit alarm) and designed for continuous application at a maximum temperature of 556°C. The average steam pressure is 15.17 MPa(g), with an allowable stress of 67.4 MPa(g) and the outer diameter (OD) of the tubes is 42x8 mm.

One of the most frequent causes of power plant shutdown is boiler tube leaks caused by poor thermal conductivity due to a buildup of deposits on the inside of the pipe led to higher tube metal temperature (Ghosh et al., 2010; Xue et al., 2020), excessive hoop stress due to overheating changed the microstructure the subsequently increased the mechanical properties of the tube (Akbar et al., 2023; Pramanick et al., 2017), the soot blower did not work properly (Rahman, 2013), and the use of inappropriate pipe materials (Antono et al., 2018). Understanding the root causes of these failures concerning design, material quality, and fabrication procedures is imperative for enhancing equipment reliability, availability, and safety, thereby safeguarding against substantial financial losses across industries (Carlson, 2012; King, 2016; Sutton, 2014).

The objective of this research is to find and investigate the failure analysis that occurred on the platen superheater of unit 2 at Coal Fired Power Plant (CFSPP) South Sumatra-V. It is needed in order to find out the troubleshooting and benefits of improvement that undertaken.

Research Method

Visual Examination

This research begins with a visual examination and measurements of wall thickness. Visual inspection involves directly observing the damage pattern and shape to locate the point of damage in the field. Wall thickness measurements are conducted to evaluate the effect of operational conditions on the thickness of the tube wall.

Laboratory Test

The investigation proceeded by sending samples of the failed platen superheater tubes to the laboratory for material testing. The laboratory tests included: Chemical composition testing using Optical Emission Spectrometry (OES), hardness testing using

Rocky DR, tensile testing using Shimadzu, metallography testing using Optical Microscope and Optical Macroscope, fracture surface examination using Scanning Electron Microscope (SEM), and compound analysis of tube deposits using X-ray diffraction (XRD).

Additional Refractory

Based on the findings from the analysis of tube failure in the platen superheater tube, improvements were made by adding refractory material to the platen superheater panel in the furnace. This addition of refractory material was carried out during the maintenance outage of Unit 2 in the period of July-August 2023.

Boiler Efficiency Assessment

Two generally accepted methods for determining the efficiency of a steam generator are the Input–Output method and the energy balance method. The choice between the methods should be based on the available instrumentation and expected test uncertainty (Performance Test Codes, 2013). By considering the availability of data and instrumentation installed on the South Sumatera-V boiler as well as the ease of work, an efficiency assessment was carried out using the Input-Output method with the following equation:

$$Efficiency = \frac{Output}{Input} \times 100 \quad (1)$$

$$Efficiency = \frac{(m_{MS} \times h_{MS}) + (m_{HRH} \times h_{HRH}) + (m_{AUX} \times h_{AUX}) + (m_{BLW} \times h_{BLW}) - (m_{FW} \times h_{FW}) - (m_{CRH} \times h_{CRH}) - (m_{SHS} \times h_{SHS}) - (m_{RSH} \times h_{RSH})}{Coal\ Flow \times Coal\ High\ Heating\ Value} \times 100 \quad (2)$$

Where,

m	: Flow (ton/hr)	CRH	: Cold Reheat Steam
h	: Enthalphy (kJ/kg)	AUX	: Auxiliary Steam
MS	: Main steam	BLW	: Blowdown
FW	: Feed water	SHS	: Superheater Spray
HRH	: Hot Reheat Steam	RSH	: Reheater Spray

Results and Discussion

Visual Examination

The sample of Platen Superheater (PSH) tube divided into straight and elbow tube. The exterior of the straight PSH tube is visually examined and the result shown in Figure 2. The exterior has two different conditions which are damaged side and no-damaged side. The no-damaged side show uniform condition where there is no removed material and no change in color. Meanwhile, the damaged side show the non-uniform condition where removed material is observed and also corroded surface shown as area with red-brown color. There are also cracks observed on the surface of the tube which are suspected as cracks on the oxide layers of the tube since it is shown as a removed layer from the tube surface instead of the through wall crack.

The condition of the elbow tube is as shown in Figure 3. It can be seen that the black deposits forming a texture similar to sludge that sticks on the inner diameter surface of the elbow tube.

Figure 2. Exterior straight tube condition

Figure 3. Elbow tube condition

Chemical Composition

The material of straight and elbow PSH Tube as shown in Table 1. comply with the chemical composition of Grade 12CrMoVG material according to Standard GB 5310 (*The Standardization Administraion of the People's Republic of China, GB 5310-2008 National Standard of the People's Republic of China Seamless Steel Tubes and Pipes for High Pressure Boiler*, 2009).

Table I. Chemical Composition Test Result of The PSH Tube

Sample Code	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Mo (%)	V (%)
Straight tube	0.092	0.233	0.533	0.010	0.004	0.988	0.264	0.211
Elbow tube	0.124	0.287	0.536	0.008	<0.003	1.000	0.291	0.231
Standard								
GB 53100 Grade 12CrMoVG	0.080-0.15	0.170-0.370	0.400-0.700	0.025 max	0.015 max	0.900-1.200	0.250-0.350	0.150-0.300

Chemical Composition test result of the PSH Tube

Hardness Test

There is no standard requirement for hardness test value and results are shown in the Table 2.

Table 2. Hardness Test Result of The PSH Tube

Sample Code	Hardness
Straight Tube	83 HRB
Elbow Tube	85 HRB

Standard	
GB 5310 Grade 12CrMoVG	n/a

Hardness test result of the PSH Tube

Tensile Test

The sample for tensile test is prepared from the no-damaged side of the tube and the result value shown in Table 3. The tensile strength of PSH tube is 402 MPa which is much lower than 470 MPa as per standard. This value could be affected by the condition of the tube that has been exposed to operating condition.

Table 3. The Tensile Strength of PSH Tube

Sample Code	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)
PSH Tube	402	294	39.60
Standard			
GB 5310 Grade 12CrMoVG	470-640	255 min.	21 min.

Tensile test result of the PSH Tube

Metallography Analysis

The microstructure of PSH tube at no damaged area is observed on the exterior and interior side of the tube cross-section as shown in Fig. 4 and Fig. 5. On the exterior side, thick layer of nonmetallic material is identified since it is not affected by etching chemical. This layer is oxides that grow from the surface of the tube due to oxidation. The oxide layer is observed on the exterior and interior side indicates that oxidation had occurred on the both tube side. The microstructure of PSH tube not show ferrite-pearlite structures as usually found in carbon steel. The pearlite has been degraded where it changed into dispersed particles in the ferrite matrix. This phenomenon is usually termed as spheroidization where the lamellar structure of pearlite is fragmented into rounded-shape particles in the ferrite matrix.

Observation of the microstructure of PSH tube is also made on the damaged area. The results are shown in Fig. 6 and Fig. 7 where the oxide layer is still visible on the exterior and interior side of the tube. The microstructure is similar with the no damaged area, another important fact at this damaged area is the visible voids within the matrix. The voids are formed on the grain boundaries of ferrite matrix indicates of creep phenomenon has occurred.

X-ray diffraction (XRD) Analysis

The analysis using XRD determine the compounds in the deposits that collected from the elbow of the same line with straight PSH Tube. As shown in Table 4, the deposit samples consist of several compounds which are magnetite, hematite, silica, and pyrite.

Table 4. XRD Analysis Result of Deposit

Ref. Code	Score	Compound Name	Chemical Formula
00-003-0863	64	Magnetite	Fe_3O_4
00-001-1053	57	Hematite	Fe_2O_3
01-087-2096	28	Silica	SiO_2

Ref. Code	Score	Compound Name	Chemical Formula
00-003-0822	34	Pyrite	FeS_2

XRD test result of PSH Tube

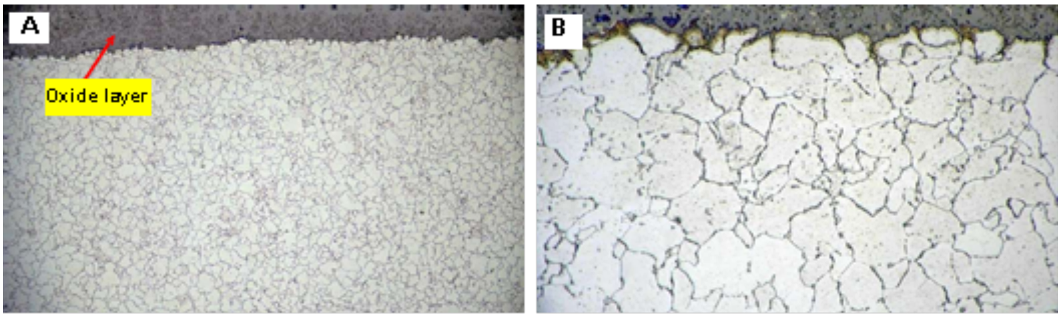

Figure 4. The microstructure of exterior side PSH tube on no damaged area under magnification of (A) 200X and (B) 1000X

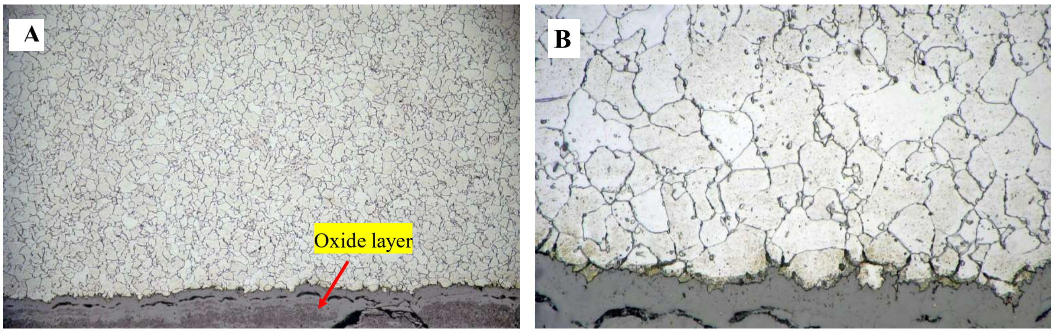

Figure 5. The microstructure of interior side PSH tube on no damaged area under magnification of (A) 200X and (B) 1000X

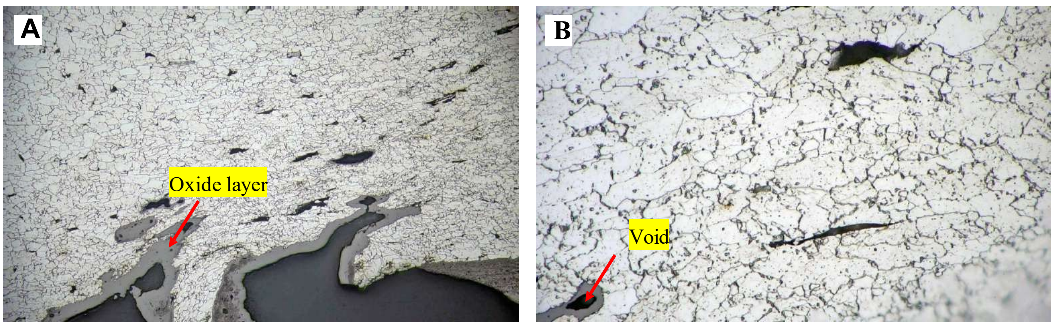

Figure 6. The microstructure of exterior side PSH tube on damaged area under magnification of (A) 200X and (B) 1000X

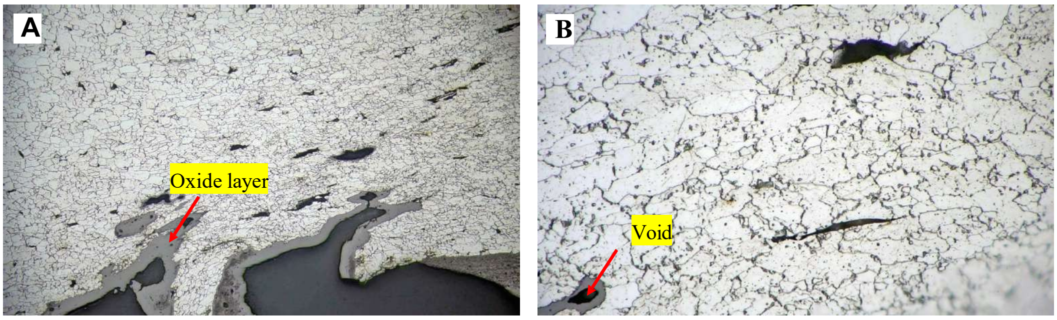

Figure 7. The microstructure of interior side PSH tube on damaged area under magnification of (A) 200X and (B) 1000X

Magnetite and hematite are the product of iron oxidation. The silica is the chemical formula of sand and pyrite is the mineral usually found in coal. Considering the pyrite as the product of Hydrogen Sulfate (H_2S) corrosion is irrelevant to the operating condition of the boiler. Since the tube flows saturated steam with temperature more than 400 ºC and there is no change for microorganism to survive under this very high temperature. Therefore, it is make sense that the presence of deposits must have been coming from the outside of the tube and somehow it enters the tube and then plug the tube.

Damage Mechanism

The damage mechanism of the leaked PSH tube is initiated by the plugging of tube elbow as shown by Fig. 8. The plugging of the tube elbow is caused by the deposits/ashes that are sticking onto the interior side of the tube make the saturated steam did not flow and consequently the PSH tube is subjected to overheating which can cause the mechanical strength of the tube drops. This overheating phenomenon is confirmed by the presence of spheroid particles in the ferrite matrix. The prolonged overheating of the tube leads to the formation of microvoids which causes cracks to form in the PSH tube and is known as creep failure. At first it is appearing as tiny voids at triple points while the three grains come together that subsequently grow out as intergranular fissures (Chatterjee, 2012).

Figure 8. Damage mechanism of PSH tube

Refractory Installation to the Platen Superheater

Based on the laboratory analysis mention before, the PSH tube failure caused by overheating due to high thermal exposure. It was observed that the refractory installed inside the furnace did not cover the PSH tube as per the design. Thus it became imperative to improve this condition by add refractory to cover the boiler tubes.

The function of the refractory is to provide insulation and protection to the PSH tubes, preventing them from being exposed to excessive heat and reducing the risk of overheating induced failures. Therefore, the rectification involved installing additional refractory into PSH tube panel number 3, 4, 5, and 6 at an elevation of 22-28 meters, spanning 2 meters in total as shown by Fig.9.

This required the use of 40,960 stud pins to secure the refractory in place. The refractory used is refractory patch castable versa flow 70 plus with maximum service temperature 1705 °C and calcined base chemical composition.

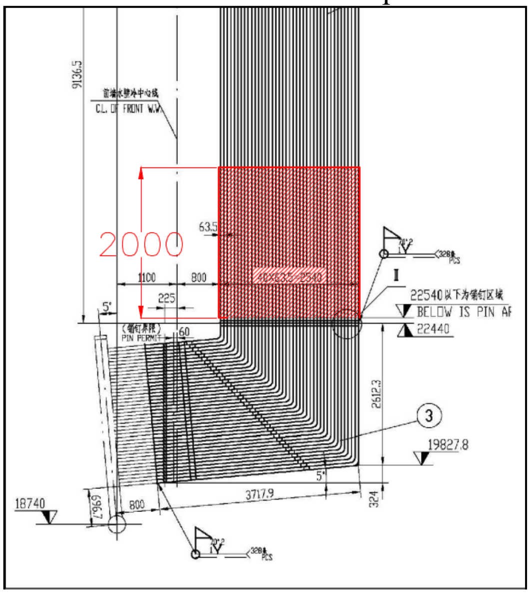

Figure 9. Additional refractory drawing

Improvement Measures

Excessive metal temperature in the PSH panel area causes high consumption of superheater spray flow and has an impact on increasing the heat rate and reducing the working efficiency of the boiler.

Monitoring results show a reduction in the use of desuperheater flow reaching 6-10 tons/day at the same load after installation additional refractory, the actual record shown in Fig 10. Three sample tubes were observed to see its effect on tube temperature. Fig. 11 show temperature exceed alarm value before meanwhile Fig. 12 shows a decrease in tube temperature reaching 15-40 °C after installation of additional refractory.

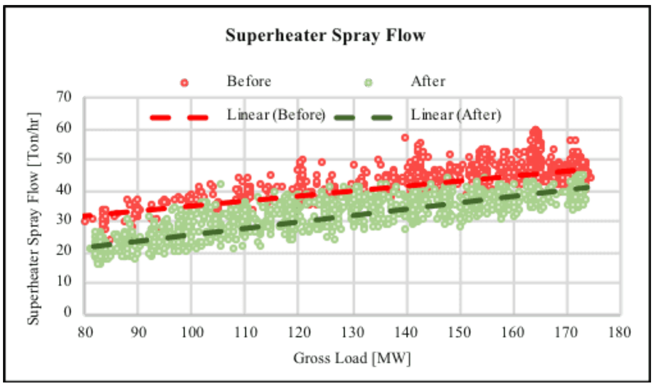

Figure 10. Superheater spray flow consumption monitoring result

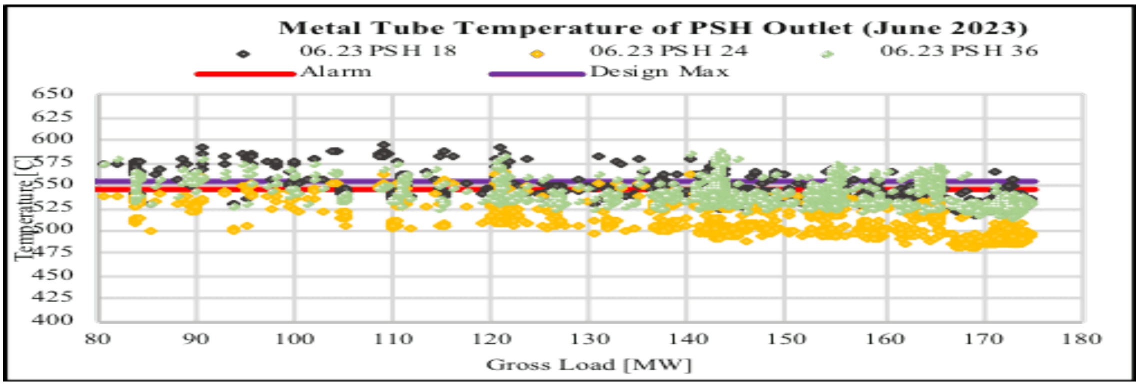

Figure 11. Metal tube temperature of PSH outlet before installation additional refractory

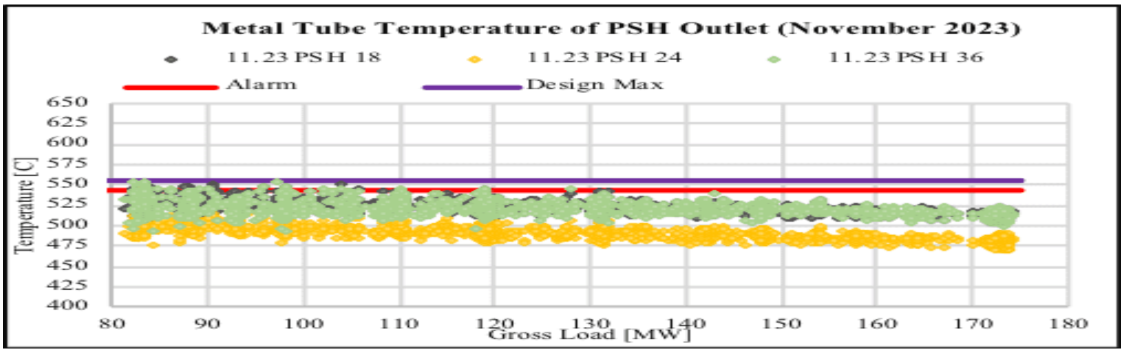

Figure 12. Metal tube temperature of PSH outlet after installation additional refractory

An assessment of boiler efficiency before and after installation additional refractory shows by Table 5. The results show that there is an increase in boiler efficiency after installing the additional.

Table 5. Boiler Efficiency Assessment Result

Parameter	Unit	Before	After
Feed Water			
Flow	kg/h	486.55	494.66
Pressure	MPa	17.70	16.93
Temperature	°C	248.96	246.70
Main Steam			
Flow	kg/h	549.40	553.35
Pressure	MPa	12.22	12.61
Temperature	°C	531.10	535.54
Cold Reheat			
Flow	kg/h	463.95	468.43
Pressure	MPa	2.94	2.86
Temperature	°C	339.83	334.33
Hot Reheat			
Flow	kg/h	484.81	486.65
Pressure	MPa	2.69	2.62
Temperature	°C	531.29	535.22
Spray SH			
Flow	kg/h	42.81	38.99

Parameter	Unit	Before	After
Pressure	MPa	15.06	15.73
Temperature	°C	173.48	172.84
Spray RH			
Flow	kg/h	20.86	18.22
Pressure	MPa	4.72	5.19
Temperature	°C	171.50	170.43
Coal Consumption			
Coal Flow	kg/h	133.39	135.22
HHV	kcal/kg	3420	3405
Boiler Efficiency		**83.19%**	**83.54%**

Boiler efficiency assessment result before and after improvement implementation

Conclusion

The investigation into the causes of the platen superheater (PSH) tube failure at Unit 2 of the coal-fired power plant in South Sumatra showed that deposits and ashes clogged the tube causing overheating and reducing the strength of the tube. After improvements during maintenance, like adding refractory material, the tube's temperature decreased by 15-40°C, bringing it to a normal range. This also reduced desuperheater flow consumption by 6-10 tons/day at the same load, and boosted boiler efficiency from 83.19% to 83.54%. This success emphasizes the importance of thorough investigations and proactive maintenance to ensure reliable plant operation. Continuing to follow best practices will be key to maintaining performance and minimizing downtime.

Acknowledgment

The authors gratefully acknowledge Mr. Lyu Yong Jun (CTO) and Mr. Chong Chee Shang (IPP Plant Head) for their continuous effort in the characterization part of the paper and their constant source of inspiration in writing it. The authors are also grateful to all personnel at PT DSSP Power Sumsel for providing the information necessary for the completion of this work.

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