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Evaluation and Analysis of the Remaining Life of the Superheater Area Tube Boiler Using the Corrosion Rate Calculation Method

Firman Yunan Saputra[1], Arrad Ghani Safitra[2*]

[1,2]*Department of Mechanical and Energy Engineering, Politeknik Elektronika Negeri Surabaya, Jl. Raya ITS, Sukolilo, Surabaya 60111, Indonesia*

**Corresponding author: Arrad Ghani Safitra; email: arradgs@pens.ac.id*

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Abstract – *In coal-fired power plant operations, maintaining the temperature stability of components is crucial for system efficiency and reliability. The superheater serves as a secondary heater for dry steam. One cause of reduced thermal performance is the non-uniform wall thickness of the pipes at various points. This study aims to determine the rate of pipe wall thinning in the superheater at panel 1 as sample area by 2027 using pipe wall thickness data from the 2025 overhaul inspection. The analysis results show that the highest corrosion rate occurs at point D in 2027, with an average of 0.27, resulting in a thinner pipe wall at that point compared to the other pipes. This thickness variation is related to corrosion and erosion caused by fluctuating operating loads.*

Keywords: *Corrosion Rate, Remaining Life, Superheater, Thickness*

I. INTRODUCTION

A reliable electricity supply is one of the main pillars supporting economic development and public welfare. According to the Ministry of Energy and Mineral Resources (ESDM), the national power generation capacity has increased by 7 GW, which has had a positive impact on public access to electricity in various regions of Indonesia [1]. This growth in capacity requires the power generation system to operate optimally and reliably in order to avoid service disruptions that could harm various sectors.

In power plants—particularly steam power plants (PLTU) and steam-using process industries—boiler components play a crucial role as a source of high-pressure steam [2]. The efficiency and smooth operation of the boiler greatly determine the overall performance of the system. Although boiler thermal efficiency can be high in theory, operational implementation often faces challenges related to the reliability of internal components, particularly boiler tubes that bear extreme thermal and mechanical loads [3]. Boiler tubes—which include waterwall tubes, superheaters, reheaters, and economizers—are located in critical zones due to their direct contact with hot fluids and combustion products. Tube damage, such as leaks, cracks, and thermal fatigue, frequently leads to shutdowns, disruptions in grid supply, and increased maintenance costs. These issues impact not only technical aspects but also the operational and economic aspects of power plants.

Maintenance methods generally still rely predominantly on a time-based preventive maintenance approach or corrective maintenance after a failure occurs [4]. These approaches have limitations in detecting failures early or accurately predicting the service life of tubes, given that failure characteristics are often random and influenced by varying operational conditions [5]. Historical data often show that many tube failures occur outside the predetermined service intervals, making these approaches often ineffective in preventing functional failures.

To address these limitations, a more systematic approach is needed—such as a quantitative approach capable of analyzing failure patterns, calculating reliability levels, and helping to determine proactive rather than reactive maintenance strategies. Several studies have shown that the application of reliability analysis can improve availability, reduce failure rates, and optimize maintenance costs in boiler systems, particularly for critical components such as tubes [6].

Based on the above conditions, the focus of this study

is the evaluation and analysis of the remaining life of boiler tubes in the superheater area of unit 2 using the corrosion rate calculation method as a form of verification to reduce losses due to boiler tube failures and support the power plant's increasingly higher performance. This approach is expected to yield more effective maintenance strategies based on actual failure patterns, as well as more accurate and cost-effective service interval recommendations.

II. Method

In this study, the forecasting process was conducted by systematically sampling thickness data from the superheater tubes, specifically at 6 rows and 6 different measurement points, as shown in Fig. 1. Thickness data was collected using a Krisbow QPUT1 ultrasonic thickness gauge, which offers an accuracy of ± (0.5%H + 0.01) mm with a measurement range of 0.7 to 300 mm for detecting metal material thinning due to corrosion or erosion during boiler operation. The superheater pipes studied were made of ASTM A213/A213M Grade T22 with an outer diameter (OD) of 50.8 mm. According to the ASTM A213/A213M standard, Grade T22 has specific chemical composition limits, including 1.90–2.60% chromium by weight and 0.87–1.13% molybdenum by weight. The minimum tensile strength and minimum yield strength specifications for this material are 415 MPa and 205 MPa, respectively, with a minimum elongation of 30%.

These thickness measurements can only be performed when the power generation unit is not in operation—that is, when the unit is shut down or undergoing maintenance or overhaul—so that access to the surface of the superheater tubes can be safely conducted and the measurement results obtained are more accurate and representative to support subsequent predictive analysis.

The thickness data obtained will be used as the basis for calculating the corrosion rate at each measured point, followed by a thickness prediction for corrosion during the next inspection period. Based on these predictions, the remaining life is estimated to evaluate the level of material degradation and identify areas that may reach the Minimum Wall Thickness (MWT) limit. This approach allows for a quantitative evaluation of the integrity of the superheater tubes, thereby supporting the development of condition-based inspection and maintenance strategies.

All thickness data obtained were analyzed using a corrosion rate analysis approach by calculating the long-term corrosion rate based on the difference between the initial thickness and the actual thickness at each measurement point. These corrosion rate values were then used to predict the tube thickness at the next inspection period and to calculate the remaining life until the Minimum Wall Thickness (MWT) limit is reached. The calculation results for each point were then compared to identify the distribution of material degradation, determine critical areas with the highest thinning rates, and evaluate the potential for tube failure as a basis for developing condition-based inspection and maintenance recommendations.

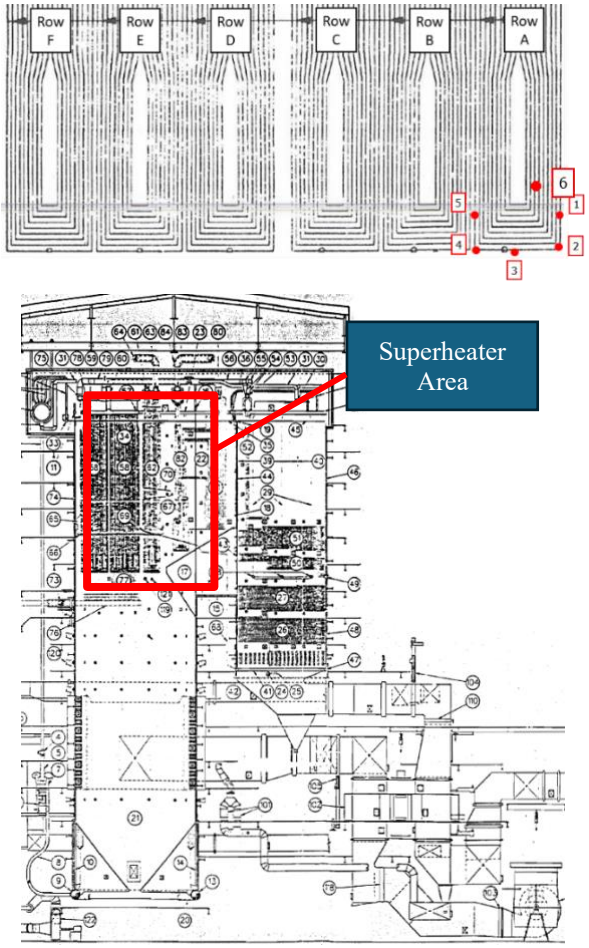


Fig. 1. Tubes superheater: (a) measurement rows and points on division platen tubes, (b) boiler overview

A. Corrosion Rate

The corrosion rate is the rate at which a metal is eroded due to reactions with its surrounding environment; it is determined by comparing two thickness measurements and dividing that difference by the time interval between the measurements. Determining the corrosion rate may involve thickness data from two different time points.

a. Long-Term Corrosion Rate

Long-term refers to a comparison of the most recent reading with a reading taken earlier in the equipment's service life. Here is the equation used:

$$Corrosion\ Rate\ (LT) = \frac{t_{initial} - t_{actual}}{Time} \quad (1)$$

Where,
$t_{initial}$ = initial thickness (mm)
t_{actual} = actual thickness (mm)
Time = time period ($t_{initial}$ - t_{actual}) (year)

b. Short-Term Corrosion Rate

The short-term trend is typically determined by the two most recent thickness readings. Here is the equation used:

$$Corrosion\ Rate\ (ST) = \frac{t_{previous} - t_{actual}}{Time} \quad (2)$$

where,

$t_{previous}$ = thickness measured during the previous inspection (mm)

t_{actual} = actual thickness (mm)

Time = time period ($t_{previous}$ - t_{actual} (year)

B. Corrosive Service

For corrosive service, the pipe wall thickness used is the actual thickness measured during the inspection, minus twice the estimated corrosion loss before the next inspection:

$$t = t_{actual} - 2(CR \times I_{internal}) \quad (3)$$

where,

t_{actual} = actual thickness (mm)

CR = Corrosion Rate

$I_{internal}$ = inspection intervial (year)

C. Remaining Life Calculation

Remaining life calculation is performed to determine the estimated period during which the pipe can continue to operate safely before reaching the Minimum Wall Thickness (MWT*) limit. This analysis is based on the previously calculated corrosion rate, allowing for an estimate of when the pipe needs to be replaced or repaired:

$$Remaining\ Life = \frac{t_{actual} - t_{required}}{CR} \quad (4)$$

Where,

$t_{required}$ = required thickness (mm)

t_{actual} = actual thickness (mm)

CR = corrosion rate

III. Result

Under actual conditions in 2025, the thickness at each material point still falls within a range of approximately 6.57 mm to 8.17 mm, which generally remains within safe operational limits. However, the thickness at each point shows inconsistencies, indicating the presence of localized corrosion mechanisms. This phenomenon is supported by corrosion rate data, the majority of which falls within a low range, specifically around 0.03 to 0.13 mm/year. However, there is one point with an extremely high corrosion rate, resulting in a pipe wall thickness of approximately 4.86 mm.

As of 2026, a general decrease in thickness is observed at nearly all measurement points. At one test point, the thickness is predicted to drop to approximately 4.60 mm, which falls into the red category. The corrosion rate remains relatively stable in the range of 0.06 to 0.26 mm/year, which can still be classified as moderate corrosion. These values indicate that the degradation mechanism in that area is accelerating compared to previous levels if no action is taken. This situation suggests that, without intervention, the area has the potential to reach the minimum thickness limit in a very short time—even less than one year.

In the 2027 forecast, the degradation becomes even more severe. The thickness at one point is predicted to reach approximately 4.08 mm, which falls into the red category. In addition, several other points also begin to show a decrease in thickness ranging from 5.62 to 6.27 mm, indicating that the affected area is no longer localized but is beginning to expand. Overall, the decrease in wall thickness from 2025 to 2027 in normal areas ranges from 0.5 to 1 mm, while in critical areas the decrease is more significant. This phenomenon indicates the propagation of damage that could potentially lead to structural failure if not addressed immediately. Potential risks include tube leaks, tube ruptures, and unplanned unit shutdowns.

TABLE I
MEASURED TUBE THICKNESS IN 2025 (MM)

Point Point	Panel 1 A	Panel 1 B	Panel 1 C	Panel 1 D	Panel 1 E	Panel 1 F
1	8.17	7.86	7.89	7.85	7.93	8.01
2	6.98	6.55	6.52	6.61	6.71	6.55
3	8.02	7.76	7.87	7.89	7.89	7.90
4	6.67	6.57	6.58	6.43	6.61	6.16
5	7.75	7.95	7.92	7.89	7.96	7.70
6	7.89	7.76	7.97	4.86	7.76	7.83
Avg	7.58	7.41	7.46	6.92	7.48	7.36

TABLE II
CALCULATED CORROSION RATE IN 2025 (MM/YEAR)

Point Point	Panel 1 A	Panel 1 B	Panel 1 C	Panel 1 D	Panel 1 E	Panel 1 F
1	0.029	0.039	0.038	0.039	0.037	0.034
2	0.065	0.078	0.079	0.077	0.074	0.078
3	0.034	0.042	0.038	0.038	0.038	0.038
4	0.075	0.078	0.078	0.082	0.077	0.090
5	0.042	0.036	0.037	0.038	0.036	0.044
6	0.038	0.042	0.035	0.130	0.042	0.040
Avg	0.047	0.053	0.051	0.067	0.051	0.054

TABLE III
PREDICTED TUBE THICKNESS IN 2026 (MM)

Point Point	Panel 1 A	Panel 1 B	Panel 1 C	Panel 1 D	Panel 1 E	Panel 1 F
1	8.11	7.78	7.81	7.77	7.86	7.94
2	6.85	6.39	6.36	6.46	6.56	6.39
3	7.95	7.68	7.79	7.81	7.81	7.82
4	6.52	6.41	6.42	6.27	6.46	5.98
5	7.67	7.88	7.85	7.81	7.89	7.61
6	7.81	7.68	7.90	4.60	7.68	7.75
Avg	7.49	7.30	7.36	6.79	7.38	7.25

TABLE IV
PREDICTED CORROSION RATE IN 2026 (MM/YEAR)

Point Point	Panel 1 A	Panel 1 B	Panel 1 C	Panel 1 D	Panel 1 E	Panel 1 F
1	0.059	0.078	0.076	0.078	0.073	0.068
2	0.131	0.157	0.159	0.153	0.147	0.157
3	0.068	0.084	0.077	0.076	0.076	0.075
4	0.150	0.156	0.155	0.164	0.153	0.181
5	0.084	0.072	0.074	0.076	0.072	0.087
6	0.076	0.084	0.071	0.259	0.084	0.079
Avg	0.095	0.105	0.102	0.134	0.101	0.108

TABLE V
PREDICTED TUBE THICKNESS IN 2027 (MM)

Point Point	Panel 1 A	Panel 1 B	Panel 1 C	Panel 1 D	Panel 1 E	Panel 1 F
1	7.99	7.63	7.66	7.62	7.71	7.80
2	6.59	6.08	6.04	6.15	6.27	6.08
3	7.82	7.51	7.64	7.66	7.66	7.67
4	6.22	6.10	6.11	5.94	6.15	5.62
5	7.50	7.73	7.70	7.66	7.75	7.44
6	7.66	7.51	7.76	4.08	7.51	7.59
Avg	7.30	7.09	7.15	6.52	7.17	7.03

TABLE VI
PREDICTED CORROSION RATE IN 2027 (MM/YEAR)

Point Point	Panel 1 A	Panel 1 B	Panel 1 C	Panel 1 D	Panel 1 E	Panel 1 F
1	0.118	0.155	0.152	0.156	0.147	0.137
2	0.262	0.314	0.318	0.307	0.295	0.314
3	0.136	0.167	0.154	0.152	0.152	0.150
4	0.299	0.312	0.310	0.328	0.307	0.361
5	0.168	0.144	0.148	0.152	0.143	0.175
6	0.152	0.167	0.142	0.519	0.167	0.159
Avg	0.19	0.21	0.20	0.27	0.20	0.22

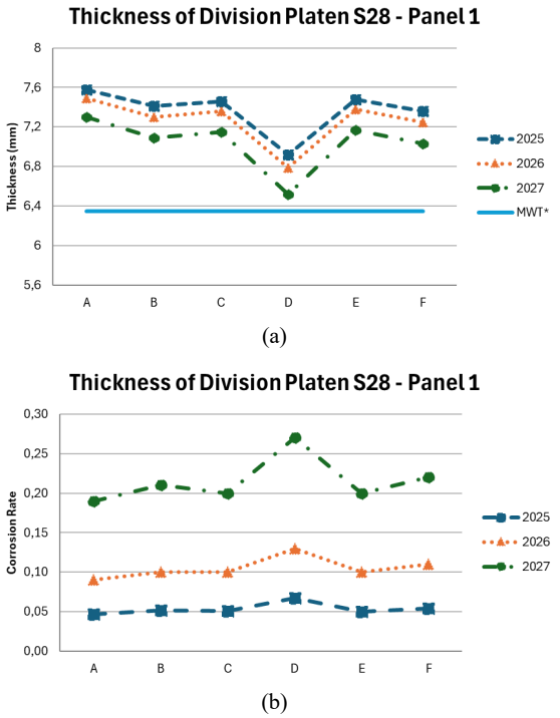


Fig. 2. Graphic (a) Thickness, (b) Corrosion rate

The graph shows a trend of pipe wall thickness thinning over the years. The greatest thinning occurs in 2027, but the condition is still considered safe because it remains above the Minimum Wall Thickness (MWT*) limit. Localized thinning can also affect the average pipe wall thickness, as shown in row D, which has the thinnest wall thickness compared to the other columns. Furthermore, the highest corrosion rate occurs in 2027, indicating that pipe wall thickness also affects the material's ability to withstand boiler operating loads.

1. $Remaining\ Life\ A = \frac{9{,}14 - 7{,}30}{0{,}19} = 9{,}68\ year$
2. $Remaining\ Life\ B = \frac{9{,}14 - 7{,}09}{0{,}21} = 9{,}76\ year$
3. $Remaining\ Life\ C = \frac{9{,}14 - 7{,}15}{0{,}20} = 9{,}95\ year$
4. $Remaining\ Life\ D = \frac{9{,}14 - 6{,}52}{0{,}27} = 9{,}70\ year$
5. $Remaining\ Life\ E = \frac{9{,}14 - 7{,}17}{0{,}20} = 9{,}85\ year$
6. $Remaining\ Life\ F = \frac{9{,}14 - 7{,}03}{0{,}22} = 9{,}59\ year$

Based on these results, the remaining life calculations for each row of pipes show that under normal conditions, they still have a remaining life of approximately 9.59 to 9.95 years. Areas with high corrosion rates have a shorter remaining life than pipes with lower corrosion rates. This phenomenon indicates that thinning at each point along the pipe due to high corrosion rates leads to a decrease in the pipe's reliability and remaining life.

IV. Limitation

This assessment has limitations because it is based solely on a single reported inspection series, the lack of specific inspection dates or prior baseline data, and the absence of a Minimum Wall Thickness (MWT) calculation. Information regarding calibration records, surface preparation, and measurement uncertainties was not included in the provided documentation. The values for 2026 and 2027 are projections, not actual measurements, and assumptions regarding the rate of deterioration have not been validated with historical inspection data or operational data. Thus, although this analysis identifies critical gaps in local readings and calculations, it cannot definitively determine the remaining service life or prove specific failure mechanisms.

V. Conclusion

Based on the analysis of 2025 inspection data and the forecasts for 2026 and 2027 for Panel 1, it can be concluded that the material has undergone significant degradation, characterized by uneven local corrosion patterns. In 2027, Row D was identified as having the

thinnest thickness of approximately 6.52 mm and an extremely high corrosion rate of up to 0.27 mm/year. This value is far above the industry standard, indicating the presence of active failure mechanisms such as erosion or corrosion. However, overall, the panel can still operate for a period of 9.59–9.95 years. Based on the hypothesis that the presence of hotspots can cause extreme corrosion rates, the remaining service life of components in those areas is very limited. In addition, high operating flow rates can also increase the potential for thermal degradation.

To address these phenomena, a re-verification can be conducted during the 2027 overhaul to compare results with forecasting data; the combustion system can be optimized to reduce abrasive deposits; use a maintenance method based on historical data to identify patterns of wall thickness reduction so that re-tubing can be performed effectively, and conduct a reassessment after the overhaul of the entire superheater panel to verify the remaining service life if pipe thinning below MWT is detected.

Appendix

This study uses wall thickness data collected from the 2025 repair inspection of the superheater tubes in Panel 1, Unit 2. Thickness measurements were obtained using an ultrasonic thickness gauge on six tube rows (Rows A–F), with six measurement points on each row. The collected data was then processed to calculate the long-term corrosion rate, predict future wall thicknesses for the 2026 and 2027 inspection periods, and estimate the remaining service life based on the Minimum Wall Thickness (MWT) criteria according to API 510. The complete set of measurement data and detailed calculation tables are available from the authors upon reasonable request.

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