The Effect of Erosion on Remaining Operation Hours of Water Wall Tube of Circulating Fluidized Bed Boiler

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**Abstract.**  The piping system in a boiler is to deliver steam from the burning process to turn the turbine, which is in further operation results in electrical energy. As an important part of this electrical energy production, the piping system often has problems. One of them is erosion and it causes depletion of the pipe thickness. The depletion rate of the pipes influences their operation hours. This study is aimed to know the effect of erosion on the remaining operation hours of the water wall tube of the circulating fluidized bed boiler in a Steam Power Plant at Kupang, Nusa Tenggara Timur, Indonesia. This quantitative study uses descriptive methods to analyze and describe the data from the Non-Destructive Test (NDT) and the calculation of erosion effect on the remaining duration operation hours of water wall tube of circulating fluidized bed boiler. Results of this study show that the erosion rate significantly influences the remaining operation hours of tube waterwall furnaces. The higher the erosion rate, the shorter the remaining operation hours of the pipes and it leads to the replacement of the pipes in the short term. Therefore, the lower erosion rate results in the longer remaining operation hours of the pipes and the replacement.

**Keywords:** boiler,erosion, non-destructive test (NDT), water wall tube

# INTRODUCTION

Steam Power Plants use thermal energy to result in electrical. It is regarded as a highly efficient power plant due to the minimum maintenance on the boiler [1] [2]. The work of this power plant converts the boiling water into high-pressure steam that generates electric power through turbine [3] [4]. Therefore, the main component of a steam power plant is the boiler. It is made of steel to improve the boiler resistance toward corrosion [5] and it is designed as a sealed drum to result in high-pressure steam from boiling water [6].

Steam power plant in Kupang, Nusa Tenggara Timur, Indonesia uses circulating fluidized bed (CFB) boilers in the operational system. This type of boiler has three main parts, back pass, cyclone, and furnace [7]. The furnace plays a crucial role in the combustion process. In a CFB boiler, fuel (such as coal, biomass, or waste) is introduced into the furnace along with air or oxygen [8]. The design of the furnace allows for efficient and complete combustion. In a CFB boiler, the furnace contains a bed of particles (usually a mixture of fuel and inert materials like sand or limestone). Air or flue gas is blown into the furnace at high velocity, creating a fluidized bed where the particles are suspended and behave like a fluid. This fluidization enhances the mixing of the fuel and air, leading to more efficient combustion [9] [10] [11] [12] [13]. The furnace is designed to maximize heat transfer from the hot gases to the water or steam circulating through the heat exchange surfaces. This heat transfer is crucial for generating steam, which is used to drive turbines and produce electricity or for other industrial processes. The furnace supports the circulation of particles between the combustion chamber and the external cyclones or separators. The bed particles that are carried up with the flue gases are separated and then returned to the furnace, ensuring that unburned fuel is reused and that the bed remains at the desired temperature and composition [14]. The design and operation of the furnace are key to controlling the temperature within the fluidized bed. Maintaining the correct temperature is vital for achieving efficient combustion and minimizing emissions.

Previous studies on CFB boilers stated that it uses fluidized bed of particles for combustion. Water wall tubes are crucial components that absorb heat from the combustion gases to generate steam. Due to the high-velocity flow of particles within the boiler, these particles can erode the water wall tubes. Erosion is a significant problem as it can lead to tube wear, reduced operational life, and increased maintenance costs [15] [16] [17] [18]. It accelerates the wear of water wall tubes, leading to reduced operational hours and potential failures if not addressed. Moreover, it leads to thinning of the tube walls, which can compromise their structural integrity and heat transfer efficiency [19] [20] [21]. Therefore, it indicates that erosion can lead to higher maintenance requirements and increased operational costs due to the need for frequent tube replacements or repairs.

There are studies on the effect of erosion and wear on the water wall tubes of CFB boilers. These studies also discussed the characteristics of erosion and the wear on the water wall and the solution to avoid them. Yet, they did not study the effect of erosion on water wall tubes of CFB boilers. Therefore, this study aims to find out the effect of erosion on the remaining operation hours of water wall tubes of CFB boilers.

# METHODS

This research is quantitative study with descriptive method to analyze and describe the data of the effect of erosion on the water wall tubes of CFB boilers. The data of the water wall tubes surface was obtained from non-destructive test (NDT). The test is ultrasonic testing (UT). The calculation on the effect of erosion on remaining operation hours of water wall tubes was conducted using American Society of Mechanical Engineers (ASME) and American Petroleum Institute (API) standards. The equations used in this study is ASME B31.3-2020 Process Piping and API 210, 2016 Pressure Vessel Inspection Codee: in-service inspection, rating, repair, and alteration.

# RESULTS AND DISCUSSION

The research was conducted on a Circulating Fluidized Bed type boiler machine in the tube waterwall furnace section located at a steam power plant in Kupang, East Nusa Tenggara. Ultrasonic Testing (UT) test and measurement data were obtained from September 2018, August 2019, November 2020, and October - November 2021. In this study, interviews were conducted with the Assistant Engineer Component Analyst of the Machine who was responsible for the units in the field. Moreover, the research data was obtained from testing and measurements. The data taken were samples of several pipes on each side that experienced a decline every year. The water wall tube in the steam power plant has a new thickness of 6.0 mm with an outer diameter of 60 mm and has a safe pipe usage limit of 70% of the initial thickness of 4.2 mm. Measurements on this material are carried out once a year with data obtained from research results over a period of 4 years.

Ultrasonic testing (UT) is mostly conducted at the steam power plant in Kupang due to the ease of testing and the accurate result of the test. From the results of the test, sample data was obtained from measuring the thickness of several pipes at each elevation for 4 years which experienced a decrease. This data in **TABLE 1** will be continued to calculate the remaining operation hours and the effect of erosion of the water wall tube of the furnace.

**TABLE 1**. Pipes thickness of water wall tubes

| Year | Elevation | *FRONT* | | *REAR* | | *LEFT* | | *RIGHT* | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Tube number* | *Thickness* (mm) | *Tube number* | *Thickness* (mm) | *Tube number* | *Thickness* (mm) | *Tube number* | *Thickness* (mm) |
| 2018 | 1 | 4 | 6,17 | 37 | 6,08 | 27 | 6,32 | 1 | 6,15 |
|  |  | 56 | 6,02 | 59 | 6,02 | 30 | 6,30 |  |  |
| 2019 | 1 | 4 | 5,31 | 37 | 4,91 | 27 | 5,49 | 1 | 5,37 |
|  |  | 56 | 5,08 | 59 | 5,60 | 30 | 5,54 |  |  |
| 2020 | 1 | 4 | 5,22 | 37 | 4,75 | 27 | 5,31 | 1 | 5,11 |
|  |  | 56 | 4,75 | 59 | 5,38 | 30 | 5,14 |  |  |
| 2021 | 1 | 4 | 5,06 | 37 | 4,44 | 27 | 5,13 | 1 | 4,90 |
|  |  | 56 | 4,25 | 59 | 5,02 | 30 | 5,01 |  |  |
| 2018 | 2 | 22 | 5,59 | 23 | 5,70 | 25 | 5,43 | 5 | 5,98 |
|  |  | 46 | 5,69 | 32 | 5,61 |  |  | 9 | 5,90 |
| 2019 | 2 | 22 | 5,43 | 23 | 5,42 | 25 | 5,28 | 5 | 5,73 |
|  |  | 46 | 5,54 | 32 | 5,32 |  |  | 9 | 5,59 |
| 2020 | 2 | 22 | 5,27 | 23 | 5,14 | 25 | 5,14 | 5 | 5,49 |
|  |  | 46 | 5,40 | 32 | 5,03 |  |  | 9 | 5,29 |
| 2021 | 2 | 22 | 5,21 | 23 | 5,12 | 25 | 5,00 | 5 | 5,48 |
|  |  | 46 | 5,19 | 32 | 5,00 |  |  | 9 | 5,24 |
| 2018 | 3 | 8 | 5,62 | 13 | 5,45 | 26 | 5,80 | 4 | 5,55 |
|  |  | 50 | 5,24 | 57 | 5,51 | 30 | 5,43 | 29 | 5,24 |
| 2019 | 3 | 8 | 5,44 | 13 | 5,31 | 26 | 5,49 | 4 | 5,47 |
|  |  | 50 | 5,15 | 57 | 5,32 | 30 | 5,34 | 29 | 5,18 |
| 2020 | 3 | 8 | 5,26 | 13 | 5,17 | 26 | 5,18 | 4 | 5,39 |
|  |  | 50 | 5,07 | 57 | 5,14 | 30 | 5,26 | 29 | 5,13 |
| 2021 | 3 | 8 | 5,02 | 13 | 5,11 | 26 | 5,04 | 4 | 5,30 |
|  |  | 50 | 5,06 | 57 | 5,10 | 30 | 5,10 | 29 | 5,12 |
| 2018 | 4 | 12 | 5,54 | 1 | 5,64 | 6 | 5,81 | 2 | 5,90 |
|  |  | 31 | 5,84 | 20 | 5,50 | 30 | 5,78 | 30 | 5,46 |
| 2019 | 4 | 12 | 5,39 | 1 | 5,38 | 6 | 5,51 | 2 | 5,55 |
|  |  | 31 | 5,46 | 20 | 5,31 | 30 | 5,56 | 30 | 5,31 |
| 2020 | 4 | 12 | 5,24 | 1 | 5,13 | 6 | 5,22 | 2 | 5,21 |
|  |  | 31 | 5,08 | 20 | 5,12 | 30 | 5,35 | 30 | 5,17 |
| 2021 | 4 | 12 | 4,64 | 1 | 4,91 | 6 | 5,19 | 2 | 5,02 |
|  |  | 31 | 5,04 | 20 | 4,91 | 30 | 5,21 | 30 | 4,77 |

The erosion rate calculation is used to determine the remaining operation hours of the waterwall furnace tube which requires the value of the results of the pipe thickness measurements in the previous and subsequent years. And the time between the thickness of the previous and subsequent years. The result of the calculation is depicted in **TABLE 2**.

**TABLE 2**. Result of erosion calculation

| Year | Elevation | *FRONT* | | *REAR* | | *LEFT* | | *RIGHT* | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Tube number* | Erosion rate in  mm / year | *Tube number* | Erosion rate in  mm / year | *Tube number* | Erosion rate in  mm / year | *Tube number* | Erosion rate in  mm / year |
| 2018 / 2019 | 1 | 4 | 0,93 | 37 | 1,28 | 27 | 0,90 | 1 | 0,85 |
| 56 | 1,03 | 59 | 0,46 | 30 | 0,83 |  |  |
| 2019 / 2020 | 1 | 4 | 0,07 | 37 | 0,13 | 27 | 0,14 | 1 | 0,21 |
| 56 | 0,26 | 59 | 0,18 | 30 | 0,32 |  |  |
| 2020 / 2021 | 1 | 4 | 0,17 | 37 | 0,34 | 27 | 0,19 | 1 | 0,23 |
| 56 | 0,54 | 59 | 0,39 | 30 | 0,14 |  |  |
| 2018 / 2019 | 2 | 22 | 0,17 | 23 | 0,30 | 25 | 0,16 | 5 | 0,27 |
| 46 | 0,16 | 32 | 0,31 |  |  | 9 | 0,33 |
| 2019 / 2020 | 2 | 22 | 0,13 | 23 | 0,22 | 25 | 0,11 | 5 | 0,19 |
| 46 | 0,11 | 32 | 0,23 |  |  | 9 | 0,24 |
| 2020 / 2021 | 2 | 22 | 0,06 | 23 | 0,02 | 25 | 0,15 | 5 | 0,01 |
| 46 | 0,23 | 32 | 0,03 |  |  | 9 | 0,05 |
| 2018 / 2019 | 3 | 8 | 0,19 | 13 | 0,15 | 26 | 0,34 | 4 | 0,09 |
| 50 | 0,08 | 57 | 0,21 | 30 | 0,10 | 29 | 0,10 |
| 2019 / 2020 | 3 | 8 | 0,14 | 13 | 0,11 | 26 | 0,25 | 4 | 0,06 |
| 50 | 0,06 | 57 | 0,14 | 30 | 0,06 | 29 | 0,04 |
| 2020 / 2021 | 3 | 8 | 0,26 | 13 | 0,06 | 26 | 0,15 | 4 | 0,09 |
| 50 | 0,01 | 57 | 0,04 | 30 | 0,17 | 29 | 0,01 |
| 2018 / 2019 | 4 | 12 | 0,16 | 1 | 0,28 | 6 | 0,33 | 2 | 0,38 |
| 31 | 0,41 | 20 | 0,21 | 30 | 0,24 | 30 | 0,16 |
| 2019 / 2020 | 4 | 12 | 0,12 | 1 | 0,20 | 6 | 0,23 | 2 | 0,27 |
| 31 | 0,30 | 20 | 0,15 | 30 | 0,17 | 30 | 0,11 |
| 2020 / 2021 | 4 | 12 | 0,65 | 1 | 0,24 | 6 | 0,03 | 2 | 0,21 |
| 31 | 0,04 | 20 | 0,29 | 30 | 0,15 | 30 | 0,43 |

In calculating the remaining operation hours of the tube waterwall furnace, the actual thickness measurement value and the required or permitted thickness, and the value of the corrosion rate calculation for each pipe are required. Calculating the remaining operation hours refers to the most recent or last thickness measurement data, it is in 2021.

From the sample of measurement data regarding the thickness of the furnace waterwall tube at each elevation for 4 years obtained from the Ultrasonic Testing, a graph was obtained as in **FIGURE 1**.

**FIGURE 1**. The effect of elevation on the pipe thickness

**FIGURE 1** shows the thickness of the pipe each year which has decreased. It is known that the thickness of the pipe at elevation 1 has decreased more drastically than elevations 2,3, and 4. The pipe at elevation 1 in 2018 which was just replaced has a size of 6.02 mm. Not all new pipes have a thickness of 6.00 mm, sometimes the thickness from the factory itself can be less. In 2019 the pipe decreased in thickness to 5.08 mm. In 2020 the pipe decreased again to 4.75 mm and in 2021 the size of the pipe thickness became 4.25 mm which is very close to the safe limit of the pipe so that the pipe will soon have to be replaced with a new one. For the pipe at elevation 2 in 2018 the pipe had a thickness of 5.70 mm. In 2019 the pipe decreased in thickness to 5.42 mm. In 2020 the pipe thickness decreased to 5.14 mm and in 2021 the pipe thickness became 5.12 mm. The pipe at elevation 3 in 2018 had a thickness of 5.80 mm. In 2019 the pipe had a thickness of 5.49 mm. In 2020 the pipe thickness decreased to 5.18 mm and in 2021 the pipe thickness became 5.04 mm. While the pipe at elevation 4 in 2018 had a thickness of 5.90 mm. In 2019 the pipe thickness decreased to 5.55 mm. In 2020 the pipe thickness decreased to 5.21 mm and in 2021 the pipe thickness became 5.02 mm. The decrease that occurred from 2018 to 2019 was greater than in the following years. This is due to the lack of knowledge of boiler machine operators about how to minimize the decrease in boiler pipe thickness, so that over time operators begin to understand this knowledge so that the rate of thinning of the pipe can be even longer.

The effect of elevation on pipe thickness is very large. Like the pipe at elevation 1 which experienced a significant decrease in thickness from year to year compared to other elevations, this is because the pipe at elevation 1 which is at the bottom with a height of 6 m experienced quite a lot of erosion from the hot sand spray that continuously eroded the outer wall of the pipe. While the pipe at elevation 2 with a height of 8 m, the pipe at elevation 3 with a height of 8.5 m, and the pipe at elevation 4 with a height of 11 m experienced quite little erosion because the hot sand has a density where the spray is not much able to reach the height of the pipe at that elevation so that the decrease in pipe thickness is quite low.

**FIGURE 2**. The effect of elevation on the erosion rate of water wall tubes

**FIGURE 2** shows the effect of elevation on the erosion rate of the furnace waterwall tube. It can be seen from the graph that the pipe erosion rate at elevation 1 in 2018-2019, which was 0.83 mm/year, decreased to 0.32 mm/year in 2019 to 2020 and in 2020 to 2021 the erosion rate became 0.14 mm/year. The pipe at elevation 2, the erosion rate in 2018 to 2019 was much lower than the pipe at elevation 1, which was 0.33 mm/year. In 2019 to 2020, the erosion rate decreased to 0.24 mm/year. While in 2020 to 2021 the pipe erosion rate became 0.05 mm/year. The pipe at elevation 3 in 2018 to 2019 had an erosion rate of 0.21 mm/year. In 2019 to 2020 the pipe erosion rate decreased to 0.14 mm/year and in 2020 to 2021 the pipe erosion rate became 0.04 mm/year. Meanwhile, for pipes at elevation 4 in 2018 to 2019 the erosion rate was greater than pipes at elevation 3 but still below pipes at elevation 1 and the erosion rate was the same as elevation 2, which was 0.33 mm/year. The erosion rate in 2019 to 2020 decreased to 0.23 mm/year and in 2020 to 2021 the erosion rate was lower than pipes at elevation 3, which was 0.03 mm/year. The erosion rate obtained based on data obtained from calculations that the pipe at elevation 1 is greater than the pipe at elevations 2,3, and 4. This can be influenced by several factors causing the rate of pipe erosion at elevations that have differences and decreases every year such as the thickness of the pipe which decreases every year as in **FIGURE 4**. The distance between the previous measurement and the following measurement, the presence of very high friction of hot sand blowing on the outer wall of the pipe at elevation 1 (6 m) causes the pipe to experience a fairly high erosion rate compared to elevation 2 (8 m), pipes at elevation 3 (8.5 m) and pipes at elevation 4 (11 m) which are rarely exposed to friction of hot sand blowing and the height of the pipe position, the air speed used to blow private sand and the temperature inside the furnace which is very high. The occurrence of an incident like this really requires checking the boiler thickness, refractory inspection, and deeper knowledge about the operation of CFB type boilers which can later minimize the erosion rate even lower which can affect the longevity of the water wall tube furnace itself.

**FIGURE 3**. The effect of elevation on the remaining operation hours of water wall tubes

**FIGURE 3** shows a graph of the effect of elevation on the remaining operation hours of the water wall tube furnace in a CFB type boiler. It is known that the results of the calculation of the remaining operation hours of each elevation show that the pipe at elevation 1 has a remaining operation hour of 0.70 years. The pipe at elevation 2 has a remaining operation hour of 4.30 years. The pipe at elevation 3 has a remaining operation hour of 5.29 years and while the pipe at elevation 4 has a long remaining operation hour of 6.73 years. The remaining operation hours of the pipe at elevations 1, 2, 3, and 4 continue to increase which makes the higher the elevation, the longer the pipe replacement that must be done. Therefore, pipes at each elevation greatly affect the remaining operation hours of the pipe itself. This is because the pipe at elevation 1 (6 m) experiences very large erosion which makes the erosion rate high so that the remaining operation hours is short, while for pipes at elevation 2 (8 m), pipes at elevation 3 (8.5 m), and pipes at elevation 4 (11 m) are rarely exposed to hot sand that erodes the pipe so that the low erosion rate makes the remaining operation hours even longer. So, the higher the elevation, the longer the remaining operation hours of the pipe itself must be replaced with a new one.

**FIGURE 4**. The effect of corrosion rate on the remaining operation hours of water wall tubes

**FIGURE 4** is the effect of erosion rate on the remaining operation hours of the tube waterwall furnace. It can be seen that the high erosion rate makes the remaining operation hours shorter so that it is necessary to replace the new pipe. From the graph it can be seen that the erosion rate of the pipe at elevation 1 is 0.34 mm/year which makes the remaining operation hours 0.70 years. The pipe at elevation 2 erosion rate decreased to 0.23 mm/year which makes the remaining operation hours 4.30 years. The pipe at elevation 3 erosion rate decreased from the pipe at elevation 2 which is 0.17 mm/year which makes the remaining operation hours 5.29 years. And the pipe at elevation 4 erosion rate is very low at 0.15 mm/year which makes the remaining operation hours longer which is 6.73 years. The length of the remaining operation hours depends on the erosion rate that erodes the pipe. The higher the erosion rate due to erosion obtained from the hot sand blast from the boiler combustion, the shorter the remaining operation hours of the pipe. Meanwhile, if the erosion rate due to erosion is low, the remaining operation hours of the pipe can be longer when the pipe is replaced with a new one. Replacement of new pipes is carried out on pipes that experience very severe thinning, damage, leaks and so on. The results of the calculation of the remaining operation hours can be used as a reference to find out how long the tube waterwall furnace can be used and when the new pipe will be replaced immediately. With the results that have been determined, it can be seen that the tube waterwall furnace will be replaced earliest with a new pipe at elevation 1 which has a remaining operation hour of 0.70 years or equivalent to 8 months 4 days after the last measurement was taken.

# CONCLUSIONS

The erosion rate has a major effect on the remaining operation hours of the tube waterwall furnace. The higher the erosion rate due to erosion obtained from the hot sand blast of the boiler combustion, the shorter the remaining operation hours of the pipe. Meanwhile, if the erosion rate due to erosion is low, the remaining operation hours of the pipe can be longer before the new pipe is replaced. The replacement of new pipes is carried out on pipes that experience very severe thinning, damage, leaks and so on. The results of the calculation of the remaining operation hours can be used as a reference to find out how long the tube waterwall furnace can be used and when the new pipe will be replaced immediately. With the results that have been determined, it can be seen that the tube waterwall furnace will be replaced earliest with a new pipe at elevation 1 which has a remaining operation hour of 0.70 years or equivalent to 8 months 4 days after the last measurement was taken.

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