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IMPLEMENTATION OF ANTI-ABRASION GRID IN SUMSEL-5 580 t/h CFB BOILER (RELIABILITY AND PERFORMANCE EVALUATION)

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Abstract

CFB Boiler operated with turbulence model and fast fluidization. This model regime gives CFB boiler great heat distribution and increase boiler efficiency. Disadvantage of regime is due boiler furnace feed with coal, sand and limestone as bed material. Bed material with the high velocity and turbulence regime can be harmful for water and steam tube inside of furnace. Operational challenges such as abrasion and abrasion of boiler components will significantly affect their efficiency and increase possible force shutdown because of boiler tube leakage. This research investigated the implementation of anti-abrasion grids perpendicular to water wall tubes of Sumsel-5 CFB Boiler, installed horizontally and vertically to mitigate abrasion and enhance overall performance. The tube thickness comparison method, which was measured every outage, was used to investigate the effectiveness of the anti-abrasion grid. Since the installation of the anti-abrasion grid, the frequency of forced outages at the Sumsel-5 power plant has decreased significantly. The result showed that anti-abrasion grid installation could increase the lifespan of the CFB boiler, reduce the abrasion rate by more than 50%, and lead to enhanced boiler performance by 0,4%. Anti-abrasion grid installation could also reduce the maintenance cost due to water wall tube repair.

Keywords: circulating fluidized boiler, anti-abrasion grid, abrasion, performance enhancement

Introduction

CFB Boilers have the advantage of a highly varied use of coal, in addition to the use of other replacement fuels (Lockwood, 2013; Yue et al., 2017). Boilers with CFB type have the advantage of being efficient combustion with more clean exhaust gas emission characteristics of SO_x and NO_x content compared to other types of boilers. Besides these advantages, several drawbacks are constantly faced.

Abrasion is one of the major problems and become main failure during operation of CFB (Arjunwadkar et al., 2016). Abrasion also become reason longer outage. Abrasion is the process when material is scratched on the surface because of impacting particle (Grochowalski et al., 2023). Sumsel-5 has faced a lot of downtime because of the abrasion tube wall furnace. Total downtime from 2020-2021 is 2.374 hours and 51,30% of downtime happened because of tube leak inside of furnace.

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The circulation of solid particles in furnaces involves various fluidization phenomena, including bed movement, bubbling process, fast fluidized beds, and pneumatic transport that occurs between solid-gas phases within the furnace.

One common problem in CFB-type boilers is continuous abrasion due to direct contact between the solid particles and the tube in the boiler at high speeds. Several studies have been carried out including the installation of multi-stage anti-wear beams that are used as a coating for the impact of solid particles against the tube, or to reduce the speed of impact against tube surface (Xu et al., 2017).

Anti-abrasion coatings are used to change the regime of gas-solid flow in furnaces, some studies conducted including (Li et al., 2023), using castable anti-wear beams have been shown to stop the impact of a solid material against the walls of the water wall.

Xin Li researched the effects of metal anti-wear on water wall abrasion by using 7 anti-abrasion metal variables with type A-G (Fig 1) measured and evaluated based on the abrasion rate index, taking into account the operating effects of parameters and ash deposit altitude zones (Y.-F. Xia et al., 2013).

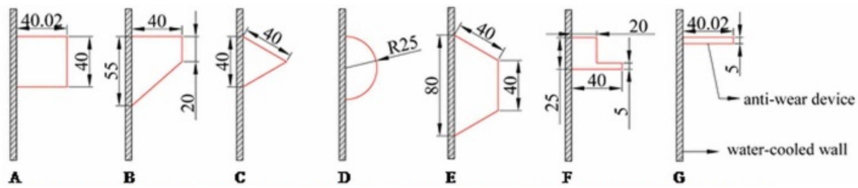

Figure 1. Different anti-abrasion metal design

One efficient way to protect against water-wall abrasion is to install multi-stage anti-wear beams on the water wall. Such beams can effectively disrupt the gas–solid downward flow of the wall layer in the near-wall region, reducing the downflow speed and inhibiting water-wall wear. This technology has been applied in 300 MWe CFB boilers, and good results have been shown. Several different anti-wear beam designs (Fig. 2) have been proposed (Y.-F. Xia et al., 2013; Y. Xia et al., 2015)

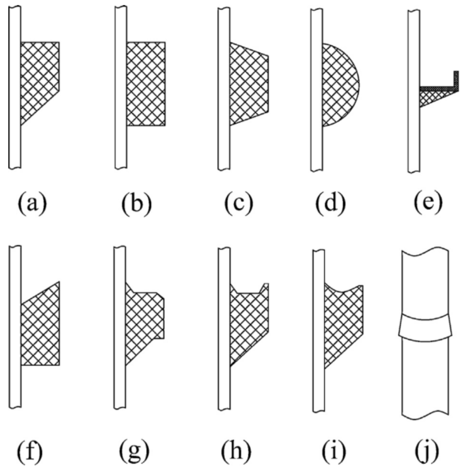

Figure 2. Different anti-abrasion beam design

Dwiputra et al implemented multiple layers of anti-abrasion beam in 100 MW Tarahan CFB Boiler. Anti-abrasion beam was proved to prevent the boiler trips caused by tube leaks, by continuously running the boiler for 6 months without tripping. Installation of anti-abrasion beam had a slight drawback on reduction of total heat rate absorbed by steam generator by around 1% (Dwiputra et al., 2012).

The efficient method to reduce the abrasion in water wall tube is pivotal to promote boiler reliability. Therefore, selection of anti-abrasion grid material and correct grid installation needs to be considered. This research discussed the implementation of anti-abrasion grid in Sumsel-5 CFB Boiler, composed of metal material and added one more type of grid installation, regarded as horizontal grid installation to improve the water wall reliability. Water wall tube thickness and boiler performance were also observed as critical indications to examine the effectiveness of the anti-abrasion grid installation.

Water Wall Tube Abrasion

Failure of waterwall tube investigated and continue analysis by center for materials processing and failure analysis faculty of engineering, Universitas Indonesia.

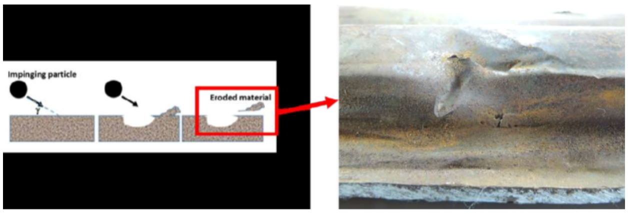

Figure 3. Abrasion mechanism and defected tube sample

The failed water wall tube was investigated and examined to observe some findings related to the failure. During examination, it was found that the outer surface of waterwall tube severely damaged with leakages observed in outer diameter surface. The damaged has been reported by abrasion that causes thinning from the outside diameter of the tube. Wall thickness reduction in some areas of the failed tubes have taken place from external surface, so this side of tube is flattened. Corrosion and damaged from internal surface diameter of tube, the damage mechanism is caused from the outer diameter of the tube. Flattening must have been caused by abrasion action.

EDS Test result on fracture surface of the sample revealed the high content of silicon (Si), indicate the presence of abrasion mechanism of waterwall tube due the solid particle. The silicon element detected in this particle was not from the tube material because it exceeded the specification of tube material. The high silicon concentration comes from the silica sand. Damage to the waterwall accelerated by fly ash entrained in the high-velocity fluidization directed against the tube surface (Y. Xia et al., 2015).

According to the operation rules and data obtained from the study, the abrasion analysis of water wall tube abrasion formula is as follows (Wuhan Yongping Technology Co., 2018): (1)

$$T = c \times n \times \mu \times w^{3,5} \times t$$

Notation T is for abrasion, c is for material abrasion coefficient, n is for material impact rate, μ is for material concentration, w is for material flow rate, and t is for time.

Heat Transfer

Installation of anti-abrasion grid can also affect the total heat transfer inside the furnace, which can be approached using following equation (Yunus & Afshin, 2015):

$$q = U \times A \times \Delta T \quad (2)$$

Notation q is for heat transfer rate, U is for overall heat transfer coefficient, A is for effective heat transfer area, and ΔT is for temperature difference. Heat transfer characteristic become key issue during this design process of anti-abrasion grid, not only to maintain efficiency of boiler, but also to maintain uniformity on boiler tubes temperature and to avoid the tubes to have overheating issue.

Heat transfer coefficient increase linier with the superficial gas velocity. The higher fluidized air flow rate will increase larger solid carrying capacity, this phenomenon contribute to increasing suspended density above the dense zone. Thus the heat transfer coefficient on the upper furnace will increases significant (Cheng et al., 2020). In other hand, considering the velocity and concentration are the most factor effecting on erosion (Song et al., 2012). The upper zone of refractory is susceptible to larger solid abrasion.

The heat transfer profile will decrease with the height of the furnace (Basu & Fraser, 2015). The additional anti-abrasion plate will change the flow of the bed material and reduce heat transfer from conduction due to the changed tube dimensions in addition of the abrasion plate. The angle of incidence of hot air from the boiler will also change slightly so the heat transfer rate calculation must be carried out to keep up boiler overall efficiency (Yang et al., 2020).

Research Method

Design Model

The design model of anti-abrasion grid consists of 3 types, comprising of vertical water wall, horizontal water wall, and horizontal split water wall. Anti-abrasion grid used for the installation composed of YP22Gr8NiRe material type.

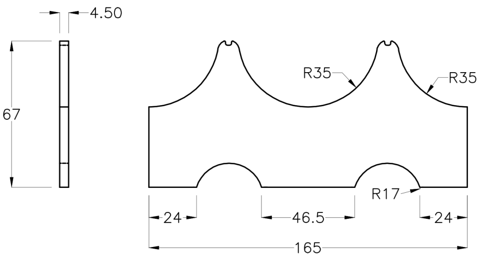

Figure 4. Design model of horizontal water wall anti-abrasion grid

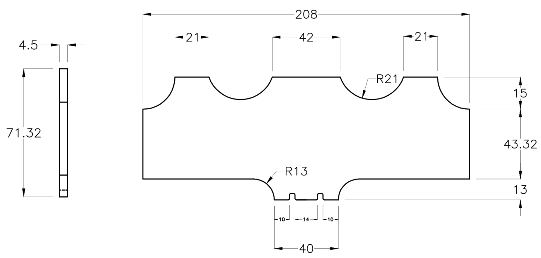

Figure 5. Design model of vertical water wall anti-abrasion grid

Figure 6. Horizontal and vertical anti-abrasion grid sample

Installation

Anti-abrasion grid was installed at elevation of 14 m until 41 m, with the distance between horizontal grid of 0,2 m; 0,6 m; 0,8 m; and 1 m. The distance between vertical grid was set to 1,2 m. Anti-abrasion grid installation was perpendicular to water wall tubes. Anti-abrasion grid installation was done on 4 sides of water wall, including on front water wall, south side water wall, north side water wall, and rear water wall.

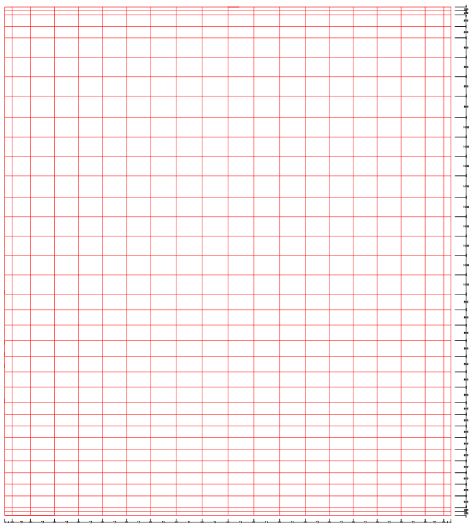

Figure 7. Schematic installation of anti-abrasion grid on front water wall

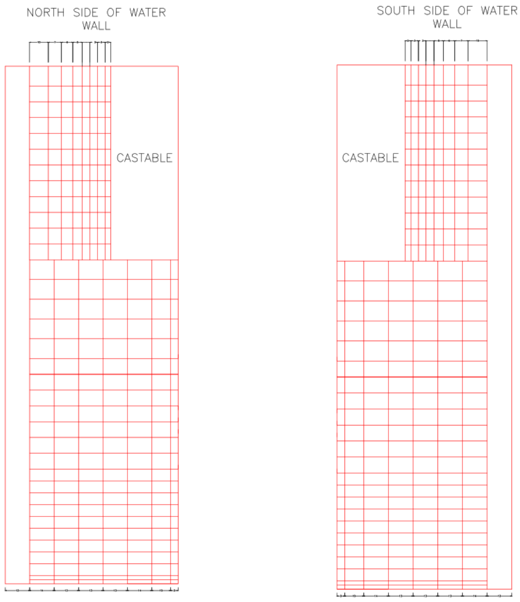

Figure 8. Schematic installation of anti-abrasion grid on north and south side of water wall

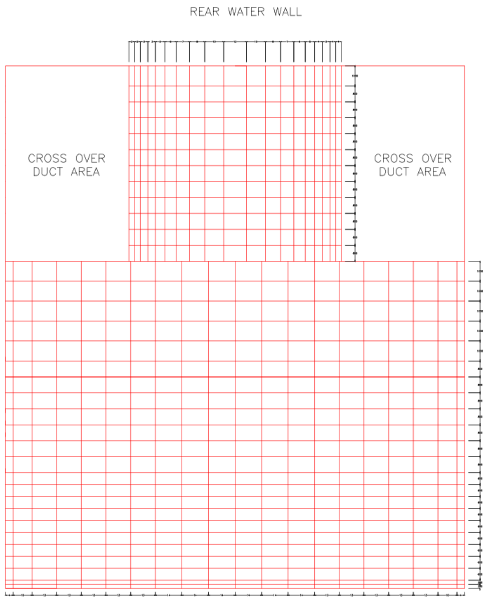

Figure 9. Schematic installation of anti-abrasion grid on rear water wall

Analysis

Tube thickness data will be taken from 2021 to 2023 to compare the abrasion rate before and after installation to see the effectiveness of the grid installation in reducing the abrasion rate in boiler water wall tube. Indirect method of boiler efficiency calculation was used as the indicator for the performance evaluation analysis, referring to the method from ASME PTC-4 [1]. Corresponding parameters will be taken right before installation in February 2022 and after installation in March 2022 to see whether any performance decrement occurs or not. The critical parameters for boiler efficiency calculation can be seen as follows:

Table I. Critical Parameters for Boiler Efficiency Calculation

Description	Unit
High Heating Value (HHV) as fired basis	kcal/kg
Low Heating Value (LHV) as fired basis	kcal/kg
Primary air rate	%
Secondary air rate	%
Fluidizing air rate	%
Air temperature entering the boiler	°C
Flue gas temperature at APH outlet	°C

Results and Discussion

Installation and Abrasion Rate Analysis

Figure 10. Installed grid in Sumsel-5

Anti-abrasion grid was installed during maintenance outage in 2022 and would be observed back in 2023 to see the effectiveness of the installation. During one year of full operation, no trip was occurred due to water wall tube leak. Visual check result also showed that no sign of significant abrasion was impacted on water wall tubes.

Table 2. Front Water Wall Tube Thickness

Tube Number	Area	Nominal Thickness 2021 (mm)	Nominal Thickness 2022 (mm)	Nominal Thickness 2023 (mm)
21	Front Water Wall (EL 21 m)	6,2	6	5,8
22		5,9	5,7	5,6
23		6,2	5,7	5,6
24		6	5,8	5,7
25		6,2	5,6	5,5
26		6	5,9	5,9
27		6,3	5,7	5,6
28		6,1	6	5,8
29		6,1	6	5,9
30		6,4	6,1	5,9
171	Front Water Wall (EL 30 m)	6,5	5,7	5,5
172		6,5	5,5	4,8
173		6,5	5,7	5,6
174		6,1	5,6	5,3
175		5,9	5,6	5,1

Tube Number	Area	Nominal Thickness 2021 (mm)	Nominal Thickness 2022 (mm)	Nominal Thickness 2023 (mm)
176		6,1	5,5	5
177		6,1	5,3	5
178		6,1	5,2	4,8
179		6,1	5,4	4,9
180		6,2	5,5	5,2

Table 3. South Side Water Wall Tube Thickness

Tube Number	Area	Nominal Thickness 2021 (mm)	Nominal Thickness 2022 (mm)	Nominal Thickness 2023 (mm)
21	South Side Water Wall (EL 21 m)	6,1	6	5,8
22		6,1	5,9	5,8
23		6,4	6,1	5,9
24		6,2	6,1	5,7
25		6,4	6,1	5,8
26		6,3	6	5,9
27		6,3	6	5,8
28		6,2	5,8	5,8
29		6,2	5,7	5,7
30		6,4	5,9	5,6
81	South Side Water Wall (EL 30 m)	6,1	5,8	5,6
82		6,1	5,6	5,5
83		6,1	5,8	5,8
84		6,1	5,7	5,6
85		6,1	5,6	5,5
86		6,3	6	5,8
87		6,2	5,8	5,4
88		5,9	5,8	5,8
89		6,1	6	6
90		6,3	5,9	5,9

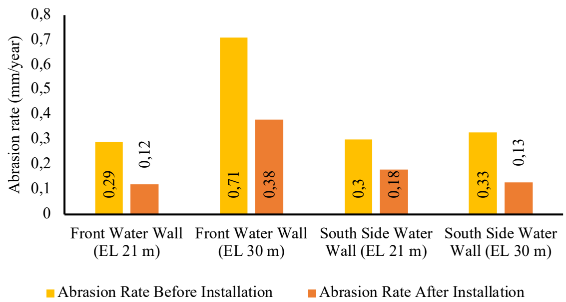

Figure 11. Average abrasion rate of water wall tubes

Table 2 and Table 3 represent tube thickness samples in front and south side of water wall tubes from 2021 to 2023. Most of the samples showed that anti-abrasion installation changed the tube thickness decrease rate significantly. Anti-abrasion grid installation is proven to cause velocity reduction of particles and simultaneously reduce contact frequency of the particles; thus, the abrasion rate can be reduced. It was also observed that all samples of tube thickness were above the thickness standard, which is 4,5 mm.

Based on Figure 11, the reduction of abrasion rate of front water wall (EL 21 m), front water wall (EL 30 m), south side water wall (EL 21 m), and south side water wall (EL 30 m) is 58,6%; 46,5%; 40,0%; and 60,6% respectively. Reduction of the abrasion rate by more than 50% had significant impact on tubes reliability, reducing maintenance cost, and increasing operation time of the CFB boiler.

Performance Analysis

Table 4. Critical Parameters for Boiler Efficiency Data

Description	Unit	Before Installation	After Installation
High Heating Value (HHV) as fired basis	kcal/kg	3.371	3.359
Low Heating Value (LHV) as fired basis	kcal/kg	2.963	2.914
Primary air rate	%	0,40	0,39
Secondary air rate	%	0,57	0,60
Fluidizing air rate	%	0,02	0,02
Air temperature entering the boiler	°C	52,71	48,35
Flue gas temperature at APH outlet	°C	131,74	133,79

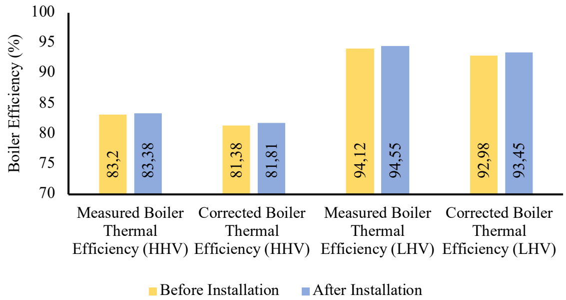

Figure 12. Boiler efficiency calculation result graph

Figure 12 presents boiler efficiency calculation results using indirect method, comparing before outage and after outage. Based on calculation result, it was observed that measured boiler thermal efficiency (HHV), corrected boiler thermal efficiency (HHV), measured boiler thermal efficiency (LHV), and corrected boiler thermal efficiency (LHV) were slightly increased by 0,18%; 0,43%; 0,43%; and 0,47% respectively. Although anti-abrasion grid installation gave a slight decrement in overall heat transfer coefficient due to less solid particle contacting on water wall tubes, along with less coal calorific value and primary air rate, it was seen that anti-abrasion grid installation helped in the increase of heat transfer area, following the heat transfer on water wall tube principal [10], so heat transfer between combustion area to water wall boiler efficiency could still be maintained at a constant magnitude.

Compared to anti-abrasion beam installation as investigated by Dwiputra et al [11], anti-abrasion grid installation gave the advantage in maintaining boiler performance of particular unit, relative to material composition and heat transfer area. The use of anti-abrasion beam could affect heat transfer area decrement due to water wall tube coverage and overall heat transfer coefficient decrement due to material composition, which is made from castable refractory. Anti-abrasion grid installation kept boiler performance since grid installed did not cover water wall tube surface area due to thin configuration. Moreover, grid installation also helped to promote heat transfer increment due to material used to make the grid, which is stainless steel-like material.

Conclusion

Anti-abrasion grid was proven to increase the unit reliability since no trips occurred due to water wall tube leak. Anti-abrasion grid installation was proven to reduce overall abrasion rate in water wall tubes by more than 50%. Moreover, anti-abrasion grid installation did not reduce overall boiler performance by slightly increasing boiler efficiency by around 0,4%.

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