CFD Modelling of Multiple Layer Anti Abrasion Beam Implementation at 100 MW Tarahan CFB Boiler

Ariyana Dwiputra, Iqbal Felani, *Member, IAENG,* Arief Syahlan and Prihadi Setyo Darmanto

***Abstract* – Since commissioning, 100 MW Coal fired Tarahan Power Plant which uses Circulating Fluidized Bed (CFB) Boiler suffered many problems, especially on water wall tubes abrasion. This condition is merely due to higher wearing rate of bed particles to the wall tubes than that of expecting design. In order to reduce wall tube wearing rate, seven layers anti abrasion refractory beam will be installed at the elevation of 16 up to 40 m around the wall tubes. Before implementation computational fluid dynamics (CFD) modeling was conducted to show the flow of the bed materials through the water wall tubes and the influence of refractory beam on heat transfer reduction was also studied. The results show that the flow of the bed material changes and tends to reduce their friction on the wall tubes without reduces heat transfer rate significantly. Since more than six months of the anti abrasion beam implementation, boiler shutdown due to wall tube abrasion was not observed yet. It means that abrasion beam installation could at least reduce significantly wearing rate.**

***Key words* – CFD, CFB, Refractory, Anti Abrasion**

I. INTRODUCTION

Tarahan coal fired steam power plant is designed using Circulated Fluidized Bed (CFB) boiler to generate 100 MW electricity. However, since few months after its first firing on, this boiler suffered wall and roof tubes thinning due to the erosion of abrasive bed and coal particles that causes eventually tube leakage. This condition implies on the boiler shutdown. The friction interaction between the bed and coal particles will wear the wall and roof tubes. Unfortunately, simultaneous mechanism of flow, heat transfer, combustion and wearing inside the boiler is very complex. This mechanism is influenced by air fuel ratio, particles abrasiveness, coal characteristic and also associated with air flow characteristic discharging from the nozzles and through the pile of bed. Due to the diversities and complexities of the flow, combustion, heat transfer and wearing rate mechanism inside of the CFB boiler, it is necessary for modeling this phenomena using CFD

Application of CFD modeling on CFB boiler has been used by P. Muscat's company since 1999 and became an essential tool since to predict burner performance and cost reduction estimation of retrofit projects [11]. In 2010, Nan Zhan group [10] was succeeding to simulate the hydrodynamics of a 150MWe CFB boiler. The simulation shows the capability of the 3D, full-loop, time-dependent CFD with emphasis on the EMMS-corrected drag coefficient, in predicting the two-phase flow behavior. SA Dude and friends prediction about Boiler Flow And Combustion (2008) demonstrated the superior mixing performance of the OFA arrangement for the proposed low-Knox combustion system, and by the year of 2009 Andrew W. Rau [12] from Foster Wheeler has been improved the CFB Boiler refractory.

Reliability of the wall and roof tubes decrease significantly with the increase of abrasion rate. In addition higher frequency on boiler shutdown reduces power to be offered to the client. It means that reduction of abrasion rate of the tubes will improve power plant reliability. It is the aim of the paper to present the CFD study on the influence of multiple layers anti abrasion beams on the flow characteristics of bed and coal particles near the tubes in order to simulate the possibility to reduce abrasion rate. The characteristics of fluid flow and particle motion in the boiler combustion chamber with and without anti abrasion beams will be simulated by CFD software and compared in order to get reasonable justification of the implementation of this proposed idea.

II. MODEL

A. *Multiple Layer Anti Abrasion Beam*

The illustration of anti abrasion layer beam is presented in Figure 1.

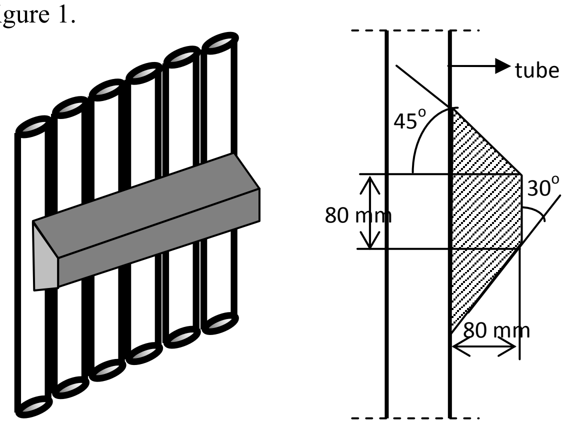

Fig 1. Illustration of anti abrasion beam on wall tubes (isometric view and cross section dimension).

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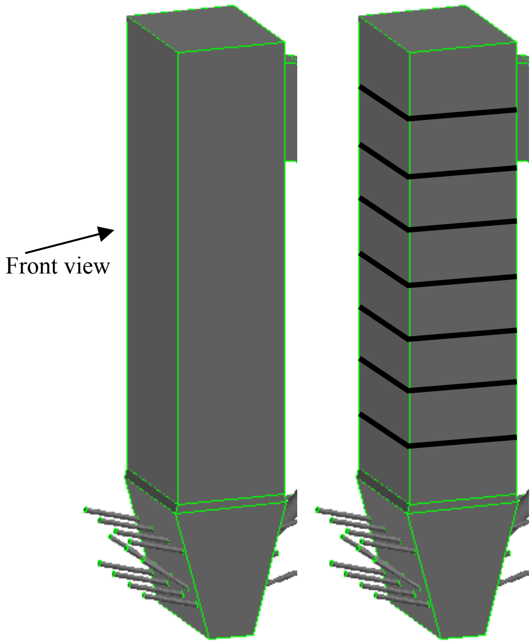
In the form of CFD modeling, the illustration of original combustion chamber is presented in Figure 2a, while the implementation of beam layers on the wall tubes around combustion chamber can be illustrated on Figure 2b.



(a) (b)

Fig 2. Illustration of Tarahan CFB Boiler without (a) and with (b) anti abrasion layer beams.

Before running to the provided software, these two models of combustion chamber should be divided into large number of small volume represented finite volume and boundary layer mesh type is applied near the wall tubes.

B. *Modeling Data*

It should be noted that CFD simulation are conducted at 100 % of capacity (design capacity). Some important data required to simulate the flow and heat transfer in the combustion chamber consist of the flow rate of primary and secondary air, heat absorption rate of the each part in the combustion chamber such as boiler, economizer and super heater panel. Heat absorption of each part is calculated based on operation data and thermodynamic properties of water or steam at inlet and outlet of each equipment [3]. The other important data is the temperature of primary and secondary air for combustion process and mass flow rate of coal. In the case of 100% load, the ratio between primary and secondary air is 60 %: 40 %. Table 1 presents numerical input data for the simulation.

TABLE I.
NUMERICAL SIMULATION DATA

Parameter	Value	Unit
Primary air flow through nozzles	209,000	m^3/h
Primary air flow through coal feeder	15,000	m^3/h
Secondary air flow	148,900	m^3/h
Air flow through seal port	10000	m^3/h
Primary air temperature	225	C
Secondary air temperature	253	C
Coal flow	49	ton/h
Coal calorific value	5,000	kcal/kg
Boiler heat absorption	116,000	kW
Economizer heat absorption	42,705	kW
Super heater heat absorption	43,500	kW

III. RESULTS AND DISCUSSION

A. *CFD Simulation*

Anti abrasion layer beams will be installed at the elevation of 16 m, 20 m, 24 m, 28 m, 32 m, 36 m, and 40 m around wall tubes in the combustion chamber. It is expected that the path lines of the particles change after hit the beams and tend to pass away from wall tubes that imply on the reduction of wearing rate of the tubes. In order to get more understanding on the flow distribution inside the combustion chamber, the CFD simulation results will be presented at diagonal cross section and other cross sections presented in Figure 3. The facade of this figure shows the rear view of the boiler.

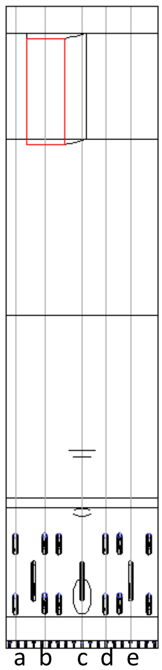


Fig 3. Cross sections selected for presentation CFD simulation results.

The velocity distribution of bed and coal particles along the diagonal cross section of the combustion chamber is presented respectively in Figures 4 up to 7 in the form of vector and contour both for the original condition (without beams) and with the beams.

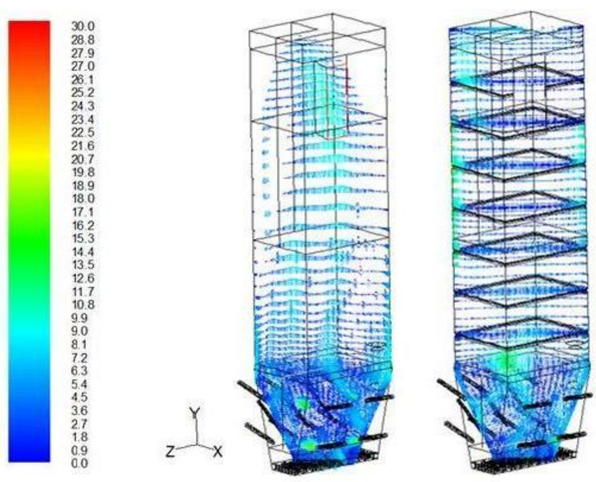


Fig 4. Particles velocity vector (m/s) at the rear view diagonal cross section of the combustion chamber.

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These figures mention that the implementation of anti abrasion layer beams could change particles velocity distribution inside of the combustion chamber. In the original condition, lower velocity exists at the region near the wall, while using beams the velocity distribution seems to be more uniform. It is eventually due to the beam form that could accelerate particles and change their direction through away from the wall. With the lower particles average velocity, it is expected that qualitatively wearing rate of the tubes becomes lower.

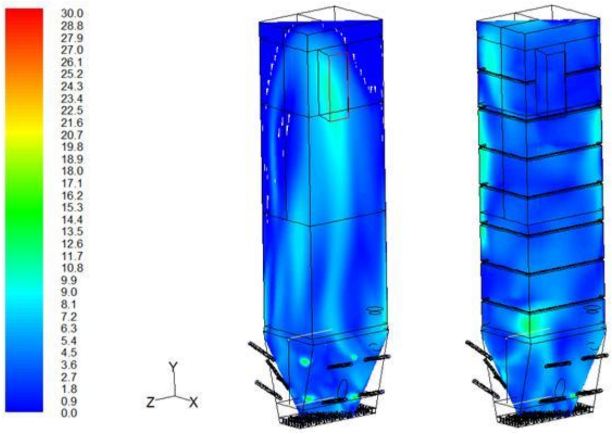

Fig 5. Particles velocity contours (m/s) at the rear view diagonal cross section of the combustion chamber.

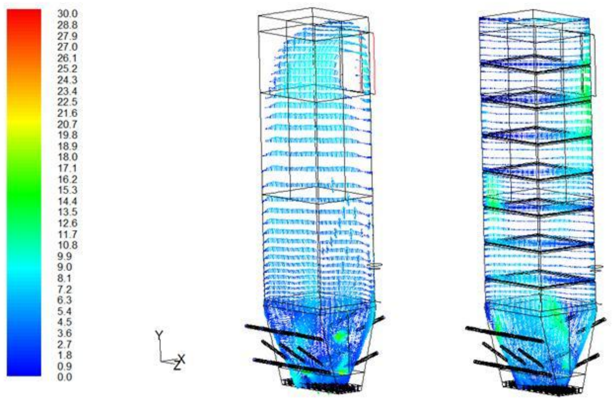

Fig 6. Particles velocity vector (m/s) at the front view diagonal cross section of the combustion chamber.

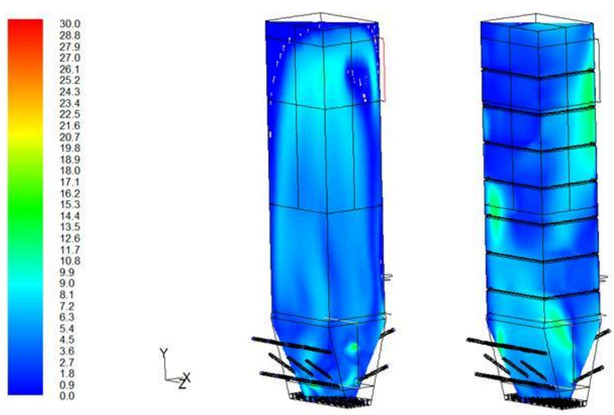

Fig 7. Particles velocity vector (m/s) at the front view diagonal cross section of the combustion chamber.

Figures 8 up to 12 represent the CFD simulation results in term of particles velocity distribution contours at some cross sections mentioned in Figure 3. As mention in figures before, even in these cross sections, implementation of anti abrasion beams changes the distribution of particles velocity to be more uniform except in cross section a due to the strong suck from the cyclone part at the top part of the combustion chamber. In order to observe more clearly the flow of particles near the wall, especially around the beams, the detail velocity vector of the particles is also presented. Figure 13 shows the velocity vector distribution at the boundary layer region around two top beams at the surface near cross section a mentioned in Figure 3, while for the condition around two middle beams and two lowest beams are represented respectively in Figures 14 and 15.

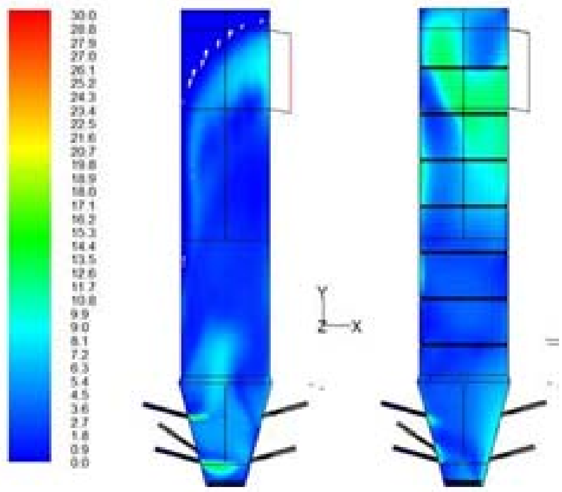

Fig 8. Particles velocity contours (m/s) at the **a** cross section of the combustion chamber.

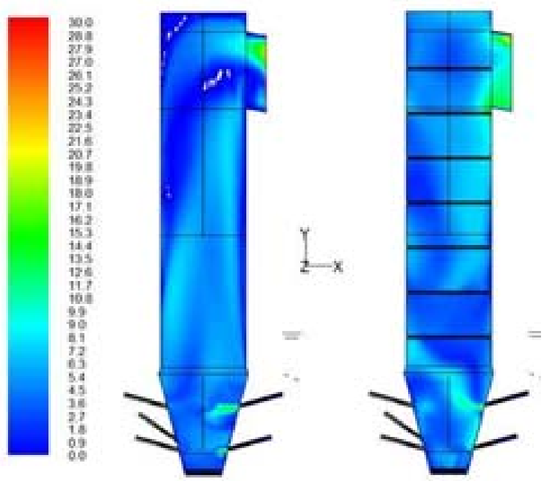

Fig 9. Particles velocity contours (m/s) at the **b** cross section of the combustion chamber.

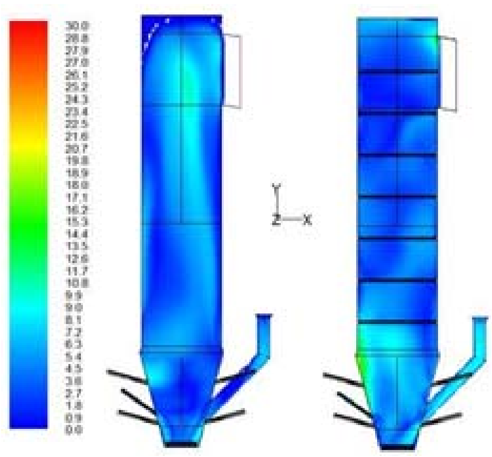

Fig 10. Particles velocity contours (m/s) at the **c** cross section of the combustion chamber.

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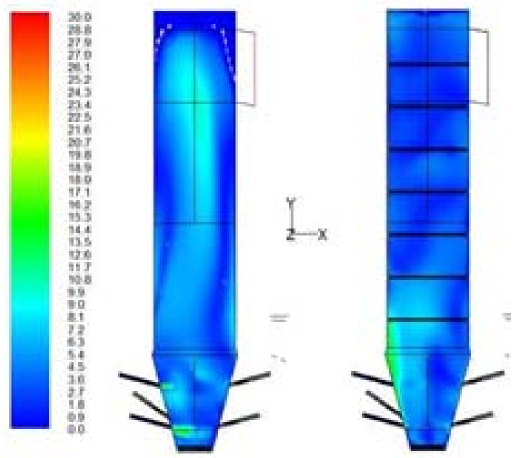

Fig 11. Particles velocity contours (m/s) at the **d** cross section of the combustion chamber.

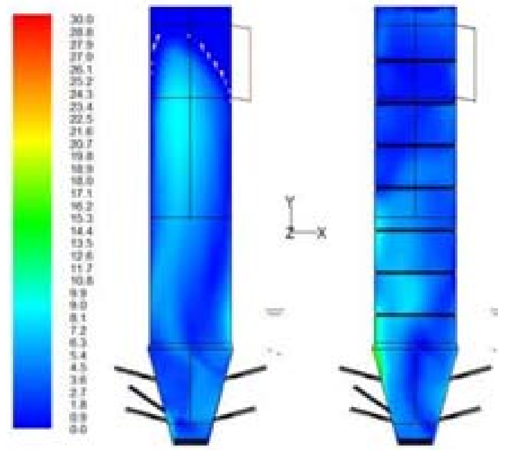

Fig 12. Particles velocity contours (m/s) at the **e** cross section of the combustion chamber.

At the cross sections d and e, especially in the upper part of the combustion chamber using anti abrasion beams, the velocity of the particles is lower and more uniform than that of original condition without anti abrasion layer beams. With the lower speed of particles it is once more expected that wearing rate of the wall tubes will decrease. In more detail, Figure 13 shows the order of magnitude of average particles velocity is about 3 m/s. With this low velocity the reduction of wearing rate will significantly increase the reliability of the tubes and simultaneously extends their technical services.

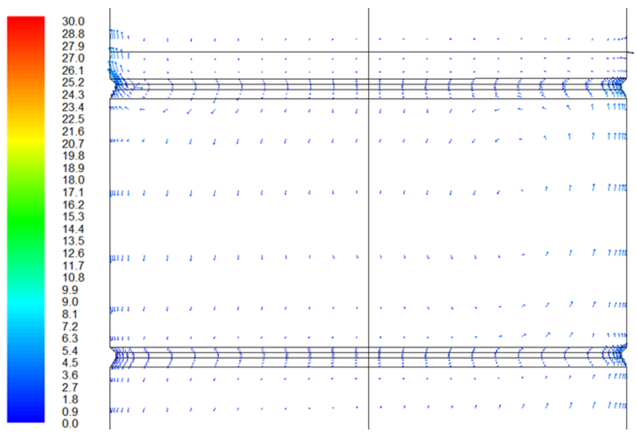

Fig 13. Particle flow velocity vector distribution (m/s) around two top beams implemented in the combustion chamber.

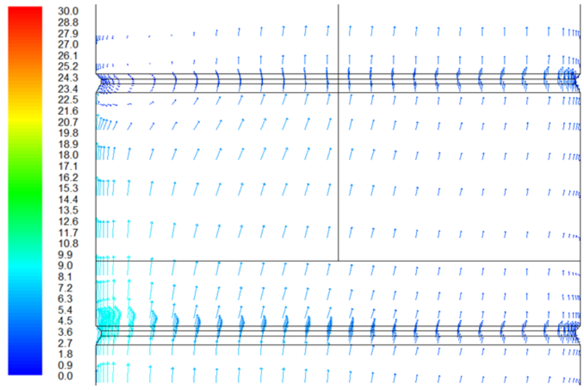

Fig 14. Particle flow velocity vector distribution (m/s) around two middle beams.

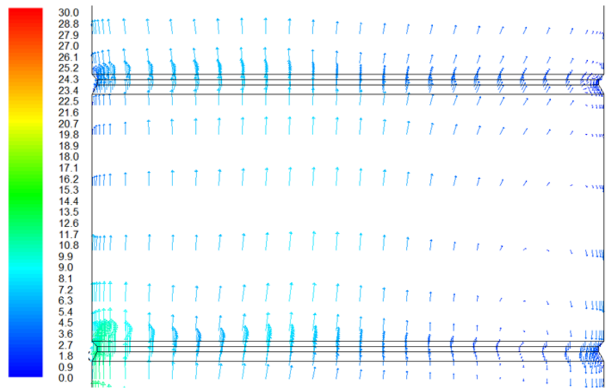

Fig 15. Particle flow velocity vector distribution (m/s) around two lowest beams of the combustion chamber.

It should be noted that almost the whole surface of this upper part combustion chamber has low particle velocity. However at the middle and lower part of combustion chamber, as depicted in Figures 14 and 15, due to the flow of return dust from the cyclone, the velocity profile at the left side of the figure (north wall surface of the combustion chamber) is higher than that of right side (south wall surface of the combustion chamber). The order of magnitude of the flow velocity of particles in the south wall is approximately 10 m/s, while for the north wall is slower which is between 1 m/s to 3 m/s. This condition will of course imply different result in term of tubes abrasion rate in which the north surface will suffer higher abrasion rate than that of south wall tubes. However, in the region between two beams, the velocity vectors of the particles near the wall tubes tend to be slower than that of center region of the combustion chamber. Thus in other word, the installation of the anti abrasion layer beams gives qualitatively a positive indication on the reduction in wear rate of wall tubes, especially at the top and the north parts of wall tubes and at the middle and lower regions of the combustion chamber.

As observed in figures 13, 14 and 15 for the east and west walls, although in the top part has particles flow rate rather high (in the range of about 9 m/s), this particles velocity in the middle and lower parts of the combustion chamber tends to slower than that of the top part. It means that in the middle and lower parts of the wall tubes in these sides, reduction of the rate of wear of wall tubes as the consequence of anti abrasion installation could also be expected.

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Finally, on the whole wall tubes, the installation of the anti abrasion beams is still profitable because almost three-quarters of the total middle and bottom wall area give the positive trend on reduction of wall tubes wearing rate by one third than that of the original condition (without anti abrasion beams). While in the top part of the combustion chamber, at least 50% of wall area are also suffered a decrease of particles flow velocity. Thus it can be estimated that the reduction of near wall particles velocity is happened at almost 65% of the total wall area which is expected to be able to decrease the rate of wear of the wall tubes at least by one third of the original condition.

B. Estimation of Heat Transfer Rate

The implementation of anti abrasion layer beams on wall tubes of the combustion chamber will cover some part of the wall and reduce heat transfer rate due to the material of beams that acts as thermal insulation. Heat transfer rate q can be approach using following simple equation (1).

$$q = \mathrm{U}.A.\Delta T \tag{1}$$

In equation (1), U is overall heat transfer coefficient in [W/m^2.K], A is effective heat transfer area in [m^2] and ΔT is temperature difference in [K]. To take into account the effect of beams installation on the overall heat transfer rate in the combustion chamber, the following approximation calculation will be discussed. The overall heat transfer coefficient U at the original condition could be approached by equation (1) as follows:

$$\frac{1}{\mathrm{U}} = \frac{1}{h_i} + \frac{x}{k} + \frac{1}{h_o} \tag{2}$$

with the following notations:

- h_i: convection coefficient at inner wall tubes [W/m2.K]
- h_o: the coefficient of convection or radiation equivalent outside wall tubes [W/m2.K]
- k : thermal conductivity of steel wall tubes [W/m.K]
- x : wall tubes thickness [m]

With the additional of anti abrasion layer beams made by ceramic material, thermal resistance at this part increases or overall heat transfer coefficient decreases. For sampler calculation, it should be noted that thermal contact resistance between the ceramic material and wall tubes is negligible. For the area covered by anti abrasion beams, the overall heat transfer coefficient $\mathrm{U_s}$ can be evaluated using the following equation (2):

$$\frac{1}{\mathrm{U_s}} = \frac{1}{h_i} + \frac{x}{k} + \frac{x_s}{k_c} + \frac{1}{h_o} \tag{3}$$

In equation (2), x_s is the average thickness of the beam while k_c denotes thermal conductivity of ceramic material. Based on the property value of these materials and heat transfer coefficient normally used in boiler design, the following data could be used for estimating the change of overall heat transfer coefficient due to implementation of anti abrasion beams, such as:

Thickness of wall tube, $x = 0.006$ m
Steel thermal conductivity, $k = 40$ [W/m.K]
Ceramic thermal conductivity, $k_c = 1$ [W/m.K]
Convection coefficient at inner tubes, $h_i = 8500$ [W/m^2.K]
Equivalent radiation and convection coefficient outside of the tube, $h_o = 250$ [W/m^2.K].

With these above mention data, the overall heat transfer coefficient for the wall tubes without anti abrasion beams U is around 234 [W/m2.K].

With the average beam thickness of about 65 mm or 0.065 m, the overall heat transfer coefficient in the part of wall tubes covered by ceramic beams $\mathrm{U_s}$ is = 14.43 [W/m^2.K]. It appears that overall heat transfer coefficient reduces up to 6.2% of the original value that could imply on the reduction of total heat transfer from hot gas to the water inside the tubes. However, because the heat transfer rate depends also on the heat transfer surface area and beams will cover small part of the whole wall tubes area, the evaluation of heat transfer rate reduction in the combustion chamber is necessary.

In this simulation the number of beams is 7 layers and placed around the boiler combustion chamber, while the total height of the boiler combustion chamber is about 41m. Due to the form of beam cross section design that is trapezium, for making simpler calculation we determine effective width of the beam with average beam thickness equal to 65 mm. Using this definition, the effective beam width is about 130 mm or 0.13 m and the beam cross section can be approached as rectangular. For 7 layers of beam, the total width of beam that covers wall tubes is about 0.91 m, or approximately is equal to 2.22% of the total height of the combustion chamber. Assuming that the temperature difference ΔT between the hot gas and the water tubes surfaces did not change significantly, the reduction of heat transfer rate in the combustion chamber due to the implementation of anti abrasion beams can be estimated as follows:

a. Heat transfer rate of wall tubes without anti abrasion beam $\mathrm{q_o}$:

$$\begin{aligned} \mathrm{q_o} &= \mathrm{U} \,.\, A \,.\, \Delta T \\ &= 234 \,.\, 41 \,.\, (\mathrm{P}.\Delta T) \\ &= 9594 \,.\, (\mathrm{P}.\Delta T) \end{aligned}$$

where P is perimeter of the combustion chamber in [m].

b. Heat transfer rate with the implementation of anti abrasion beams can be divided into two parts, wall tube uncovered and covered by anti abrasion beams. For uncovered part, heat transfer rate $\mathrm{q_{o1}}$ is equal to:

$$\begin{aligned} \mathrm{q_{o1}} &= \mathrm{U} \,.\, A_1 \,.\, \Delta T \\ &= 234 \,.\, (41 - 0.91) \,.\, (\mathrm{P}.\Delta T) \\ &= 9381.\, (\mathrm{P} \,.\, \Delta T) \end{aligned}$$

While for covered part, heat transfer rate $\mathrm{q_{o2}}$ is equal to:

$$\begin{aligned} \mathrm{q_{o2}} &= \mathrm{U_s} \,.\, A_s \,.\, \Delta T \\ &= 14.43 \,.\, 0.91 \,.\, (\mathrm{P}.\Delta T) \\ &= 13.13 \,.\, (\mathrm{P}.\Delta T) \end{aligned}$$

The total heat transfer rate $\mathrm{q_{ot}} = \mathrm{q_{o1}} + \mathrm{q_{o2}} = 9394.13 \,.\, (\mathrm{P}.\Delta T)$

In conclusion the implementation of anti abrasion beams could reduce the rate of heat transfer in the combustion chamber of about 2.08%. According to Table 1, the evaluation of heat absorbed by wall tubes is around 116 MW. So the reduction of heat transfer rate due to the implementation of anti abrasion beams is equivalent to 2.08% x 116 MW = 2.413 MW. However, at design capacity the total heat absorbed by the whole steam generator is about 240 MW. It means that the percentage of reduction heat transfer rate due to the anti abrasion beams to the total heat absorbed by steam generator is equal to (2.413/240) x 100% = 1%. This value is practically insignificant and the implementation of anti abrasion beams is seemly reasonable.

C. Plant implementation of anti abrasion beams

As mentioned in the CFD simulation results of the particles flow velocity near the wall tubes, it seems that implementation of anti abrasion beams gives opportunity to reduce wall tubes wearing rate. The reason is mainly due to the beams that act as particles flow disturbance which implies on both reduction of particles speed close to the wall tubes and change the direction of particles flow away from the wall tubes. Furthermore, simple evaluation on heat transfer rate shows that anti abrasion beams implementation reduces insignificantly total heat transfer rate inside combustion chamber. Based on the above two reasons, anti abrasion beams were decided to be installed in Tarahan 100 MW CFB boiler power plant since more than six months ago and the performance of wall tubes was also observed after installation completed. Observation on wall tubes performance shows that there was no wall tubes leakage anymore since more than six months boiler in operation. This improved performance of the wall tubes reveals us that at least the frequency of boiler shutdown due to wall tubes leakage has been reduced significantly. It should be noted that before the installation of anti abrasion beams, the time between two consecutive wall tube failures is practically not more than two months.

IV. CONCLUSION

Considering the results of CFD simulation on particles flow and heat transfer process inside combustion chamber of Tarahan 100 MW CFB boiler, the following items can be written as conclusion, such as:

1. The study of CFD simulation was conducted for two types of combustion chamber such as original type without anti abrasion beams and modified type using implementation of seven layers anti abrasion beam. The results show positive expectation related to the reduction of wall tube wearing rate, especially at almost 65% of total wall tubes heat transfer surface area.
2. Reduction of heat transfer rate due to implementation of anti abrasion beams was also evaluated using simple formulation of mixed convection and radiation. The reduction of heat absorbed by water and steam inside combustion chamber due to anti abrasion beams was also discussed. Fortunately installation of anti abrasion beams implies on the reduction of around 1% of total heat rate absorbed by steam generator.
3. The proposed idea related on the effort on reduction of wall tubes wearing rate using anti abrasion beams has already installed inside combustion chamber of Tarahan 100MW CFB boiler since more than six months ago and gives significant improvement on wall tubes performance. There was no wall tube leakage anymore during last six months operation. It should be noted that the installation of anti abrasion beams inside combustion chamber could at least reduce wearing rate of the wall tubes.

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