

THERMAL FATIGUE FAILURE IN BED EVAPORATOR TUBE OF AN AFBC BOILER

By K.K.Parthiban, B. Tech(IIT-Madras), M.E Thermal Engineering- RECT Trichy

This paper is about a repetitive evaporator tube failure experienced in an AFBC boiler. The mode of a bed evaporator tube is generally erosion or overheating or water side corrosion. But this case was thermal fatigue. Photo 1 shows the alligator skin like appearance at the failed portion. Photo 2 shows the internal longitudinal chain of cracks at 12° clock position.

The boiler parameters are 15 TPH, 44 kg/cm²g and 450°C. It is a coal fired AFBC boiler with two compartments. It has to meet the electrical load of the pulp & paper plant and the steam demand of the paper machine. Initially the plant was required to operate with single compartment for some period. Once the plant operation was stabilized, the boiler started operating to full load, specific bed evaporator tubes of 2nd compartment both on left and right side of the boiler started failing.

The failed tube locations are shown in photo 3. There are inner and outer tubes in this bed tube configuration. Only inner tubes failed.

The circulation related failures call for detailed review of trends of boiler parameters. They are mainly,

- Drum pressure fluctuations
- Drum level fluctuations
- Feed water flow at very low level
- Malfunctioning of single / three element level control
- Gas temperature profile deviations from design
- High desuperheating flow
- Fouling behavior of superheater & furnace and high FOT and Eco inlet gas temperature



Photo 1: Cracks in the tube at top side



Photo 2: Inside of failed tube

The definite proof for the cause of the Thermal fatigue mechanism could not be established due to absence of data. The DCS back was not available. Hence it was advised to collect trends on drum pressure, drum level, eco out water temperature and FCV open%, once the boiler was restarted. Hence the discussion was done, towards the possible causes of the failure.

Failed tube inspection and the mechanism of failure

The failed tube showed multiple cracks on the top part of the tube. Studs are welded at the bottom and

the top is strained on thermal fatigue. There was intermittent flow inside the tubes in a cyclic manner. The cracks that have got initiated once due short overheating cycles, have grown to multiple cracks.

Since the bed tubes are sloped, the steam blanketing occurs at top part of the tube, when the circulation is retarded. The top part of the tube will be subject to marginal overheating and

differential thermal expansion as compared to bottom part of the tube. The overheating leads to break

down of protective iron oxide exposing bare metal. The heating and cooling cycles repeat due to fluctuations in circulation rate. The flow tends to be intermittent as shown in figure 1. The flow rate of water inside the tubes must be changing in a cyclic manner. Normally when the starvation is sustained, the tube fails by overheating / creep mechanism. When there are cycles, fatigue is the failure mechanism.

POSSIBLE CYCLING OVERHEATING MECHANISM

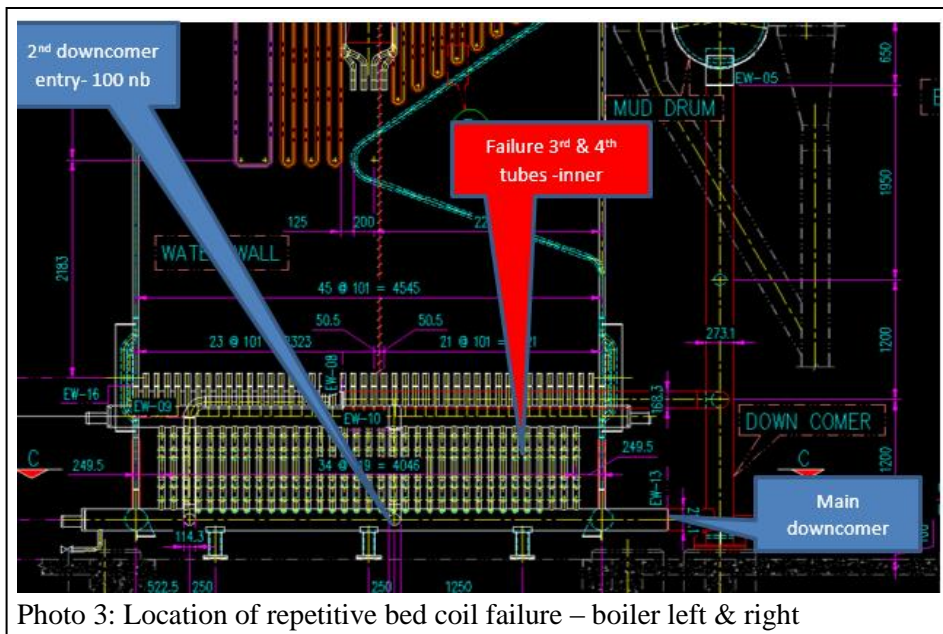


Photo 3: Location of repetitive bed coil failure – boiler left & right

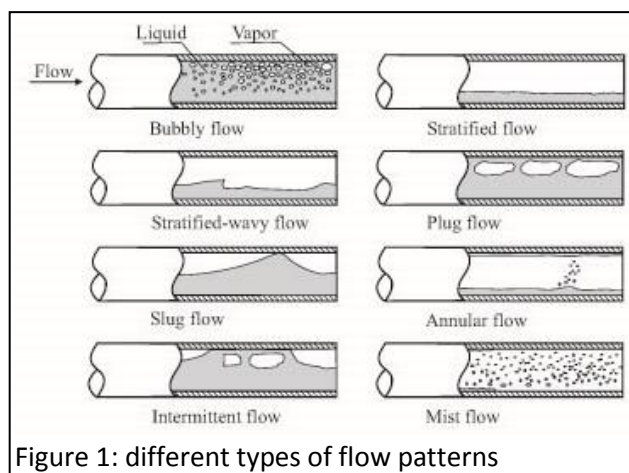


Figure 1: different types of flow patterns

Steam load pattern / drum pressure variation & flashing

The boiler is connected to the extraction cum condensing turbine. The extraction steam is for the paper mill. The quantity of steam to paper machine ranges from 8 – 12 tons. The condensing flow is maintained at 3 TPH normally. The capacity of condensation is however 6 TPH maximum. The load of boiler varies due to paper break / machine breakdown / pulp section shut down. There will be large pressure drop in drum pressure. For this reason, steam drum size should be increased. In case there is load throw, the steam generation must be reduced. When the steam flow is required to be restored, there will be considerable flashing in the steam drum due to sudden drawl. This can lead to steam bubble formation due to limited water hold up available in the steam drum. There will be swelling of water and it is called priming. Priming can cause a drop in water circulation to mud drum, from where, the water is distributed to bed coils and waterwalls. If load variation is frequent, there will be thermal hydraulic cycles.

Frequent load throw and zero feed water flow

During the period of low load operation, it becomes necessary to bring down the water flow to the

drum. It is possible that the FCV is closed on every occasion of the paper break. When the FCV is closed for longer durations, the steam drum water would not be in the state of subcooling. This can retard the circulation rate. There will be steam formation in the rear set of bank tubes which are meant to be downcomers. As the steaming occurs in the downcomer tubes, the downward flow will cease. This can lead to loss of circulation in a cyclic manner. The trends were not available to review the past data.

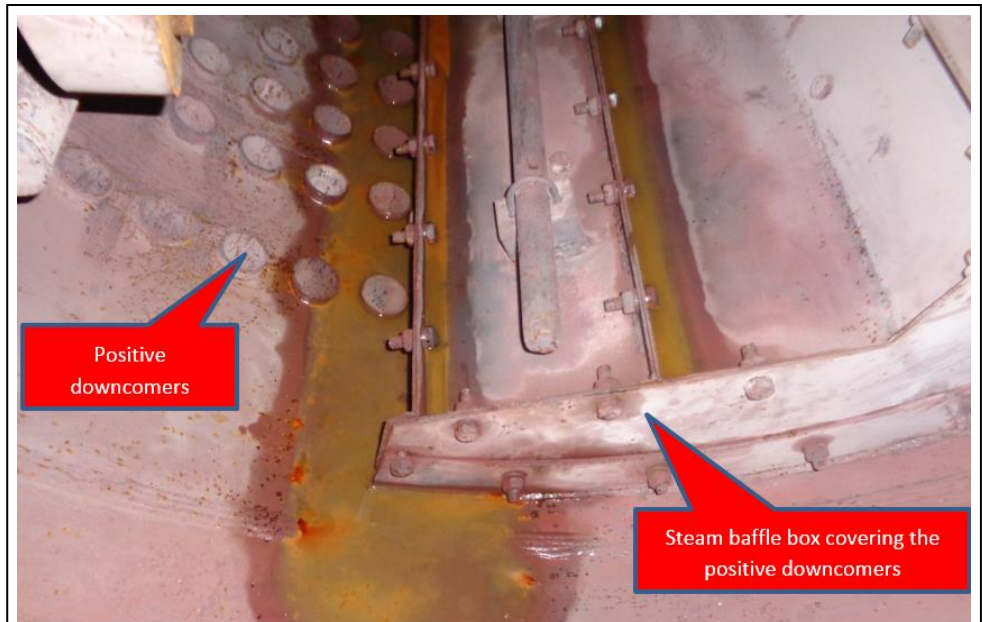


Photo 4: Positive downcomers in the steam drum

the downward flow will cease. This can lead to loss of circulation in a cyclic manner. The trends were not available to review the past data.

Changes from design temperature profile

When the boiler is overloaded, the flue gas flow is more. The heat pick-up pattern at various zone changes. When there is high excess air operation, the heat pick-up pattern changes. This also affects the circulation as the rear set of bank tubes may start steaming at times when the feed water flow is less.

Positive downcomers

Steam drum & water drum were inspected. There was a defect in steam drum internal. The positive downcomers in the front side boiler bank tubes were covered under the baffle box. See photo 4 above. The positive downcomers are insulated from heat input, by brick work in the gas path. See photo 5. Baffle box is a place where steam water mixture is available. Hence the overall circulation rate is reduced. The 180-rear set of tubes act as downcomers normally. By normal heat pick up, these are downcomers, as the water inside does not reach boiling state. The steam drum baffle was corrected in this visit itself.

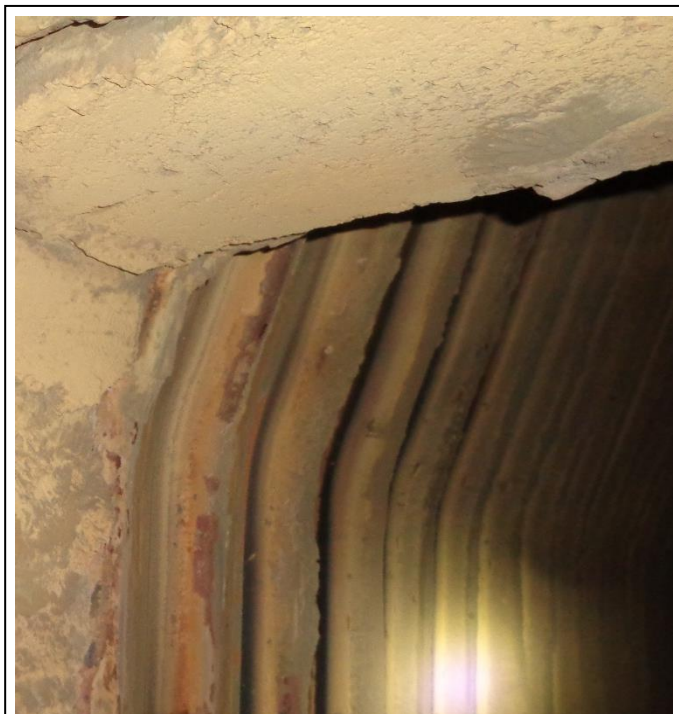


Photo 5: Brick work insulating the end bank tubes

Nose panel heat pick up & high bed temperature

The boiler is provided with nose panel which extends up to the mid of the furnace. The rear wall nose

panel views the bed considerably. This can lead to more circulation in the rearwall tubes. Thus, it could reduce the circulation in the bed tubes because the downcomer pipes are common to the rear part of the bed coils and rearwall. In the logbook, the bed temperatures were noted to be as high as 950 deg C when the load was 16 – 16.5 TPH.

Design comparison with similar boiler

As per the boiler maker, there are two other boilers of same design parameters, working elsewhere, without tube failure. The downcomer and riser arrangements were compared. There was a difference in downcomer arrangement. After pointing out the difference, the boiler maker corrected the downcomers.

Why should particular tubes fail?

The reason for the inner coil to fail is the heat flux and its outlet arrangement. The outer tube gets little more heat. The inner coil length is 1516 mm and the outer coil length is 2162 mm. The steam generation in the outer coil is more. This can obstruct the flow rate in the inner coil due to arrangement of stubs in the bed coil outlet header. Every boiler will have a difference in flow in the set of parallel tubes. Overall circulation is different from individual circulation rate in the various tubes. In this boiler, the least flow occurs in the inner coils of 3-4-5-6 tubes from furnace rear wall.

We recommended a modification in feed distributor pipe to get subcooled water to the positive downcomer zone. This was incorporated immediately by the boiler supplier.

Coal ash fouling and change in heat pick up pattern

The boiler was found to be heavily fouled as per the photos shared by the plant engineers. Ash was found to bridge between the bank tubes. Usually bank tubes are clean. It may be possible that even the rear set of banks are receiving more heat input than design. Recently the SSH was cleaned to re-align the SSH tubes. The PSH was found with less fouling. The bank tubes were found with ash fouling. The load port analysis report for the recent imported coal showed ash fusion temperature (AFT) of 1080°C. Indonesian coals of such low AFT cause heavy fouling of furnace wall tubes, SH and this leads to high bank inlet gas temperature. This can make the rear set of bank tubes to steam. It was advised to remove all the ash fouling so that the design temperature profile can be achieved.

Indonesian coal effect

The boiler engineers showed some photos taken during shut down. The bed coil studs were found coated with slag. The air nozzles were seen capped with molten ash. This is due to low AFT of the ash of Indonesian coal. There are some important things to be taken care in Indonesian coal usage.



Photo 6: Plugged air nozzles



Photo 7: Ash slag over bed coil studs

- Coal should be procured with AFT above 1300°C.
- Iron in bed ash should be less than 10%. This is to be checked by magnet. It is necessary to start the boiler with fresh bed material. From day one, the iron should be monitored, by frequent bed draining and replacing with iron free bed ash. Magnetic drums are used for this purpose.
- Bed ash bulk density should be below 1400 kg/m³. The bulk density of fresh bed material is generally around 1100 -1200 kg/m³.
- Fines and volatile matter in Indonesian coal lead to high flame at fuel feed points. Bed should be drained from all drain pipes. Compulsory draining is required at all drain points.

Circulation analysis

The circulation calculations were performed. It was found that the risers & side waterwalls are the key elements causing more pressure drop. The bed coil inlet velocity was estimated to be 0.5 m/s. Usually we target for a velocity of 1 m/s. It was advised to change the riser pipe diameter from 100 nb to 150 nb. This would increase the velocity to 0.7 m/s. However, the riser modifications were not carried out as there were two reference boilers which were operating without failure for 3 years.

SECOND VISIT

The tube failures did not stop even after the modification of the steam drum internal & the downcomer arrangement. The drum level control was found to be OK as per the trends received from the plant for next 3 months. The tubes that were replaced, failed again in the same pattern. The visit for operational review had become imminent.

The boiler was in operation at the time of visit. To our luck, all the load variations could be seen. The boiler was being fired with a combination of Indonesian coal & Indian coal.

The mechanism of tube failure could be found out in this visit. Following is the summary of observations and operational modifications carried out.

1. The boiler was in least load of about 8.5 TPH in the morning hrs. Only pulp section was in operation. There was no steam requirement at paper machine as the machine was under maintenance. One compartment was in operation. The 2nd compartment was in slumped condition. The feed water flow was coming down to 4.18 TPH in three element control. The minimum FCV % opening was at 2.38%. The minimum flow bypass valve opened once. It was advised to take the level control on manual mode at such low load situation. The startup vent was in open condition, as the steam generation was more than consumption. In the operating compartment itself there was wide bed temperature difference. One bed temperature was at 874°C and the other was at 790°C. 84°C is too large variation. The bed height in the 1st compartment was at 340 mmWC. The oxygen level was at 10.18 % which can be due to passing air from slumped compartment. The windbox pressure in 2nd compartment measured 250 mmWC. The damper leakage was too high. The economiser outlet water temperature was at a maximum of 210°C. It was not steaming. The economiser inlet



Photo 8: Low bed height operation

gas temperature was at 379 °C. The drum level was stable.

2. Then the load was increased to 16 TPH at around 11 AM. The pulp section and paper machine were in operation. The coal feed rate was kept high and fixed in first compartment. The coal feeding was being varied to the 2nd compartment. There were erratic temperatures in both 1st compartment & 2nd compartment due to this. The operator was advised to keep equal feed rate in both compartments. He was reluctant to keep different rpm as the steam temperature drops below 450°C. The bed height was at 350 mmWC in first compartment. The bed height was at 320 mmWC in 2nd compartment. There was large difference in bed temperatures. There were steam pressure variations. The rpm was being varied by the operator almost every minute. But the boiler response was very poor. The oxygen was erratic. It was ranging from 5% to 8%.
3. Around 12 noon, pulp section was stopped. The boiler load was at 12 TPH. The coal feed rates of compartments were varied without a basis by the boiler operators. In 1st compartment, the feeder rpm was at 709 and in the 2nd compartment the rpm was at 275. The fuel input to the 2nd compartment was being varied quite a lot. The steam pressure was not under control at all. The bed temperatures in 1st compartment were at 866 °C & 738°C. The bed temperatures in 2nd compartment was at 760 & 698 °C. It was explained to boiler operators, that less bed height would cause this. It was not a correct practice to vary the feeder rpm only in 2nd compartment. It was learnt that all along this was the operational practice. That answered the cycles of circulation disturbance. Every time when the firing is reduced, the heat input is reduced in 2nd compartment; the circulation gets reduced. The circulation takes time to establish back, when the coal feed is increased. This frequency was high enough to have thermal fatigue. However, FCV % opening was good with 3 element control.
4. After lunch time, operator agreed to feed same coal in both compartments. The erratic bed temperatures came down a little. The pulp section was down. However, the steam pressure fluctuation was high. Almost every minute, the boiler operator was adjusting the feeder rpm. The boiler operation was not stable. The economiser was not steaming. The economiser water outlet temperature was at 194 °C. The drum level was quite stable. The FCV opening was above 50%. Our doubt on low feed water flow was gone. Three element was working quite satisfactorily.
5. The bed height was increased to 400 mmWC. As the bed material feed rate was high, the bed temperature dropped too much. It was advised to throttle the gate below bed material bunker. The rear door was opened to see the immersion. 3/4th of the top part of the outer bed coil was visible. See photo 10. The bed height could be further increased. It was flameless combustion, which is the characteristics of fluidised bed.
6. The bed height was further raised to 420 mmWC. The PA header pressure was raised to 1075 mmWC. The vacuum was checked at the mixing nozzle and found to be OK. The feeder rpm was found to be same at field for both feeders, when the % rpm was kept same at DCS. The bed

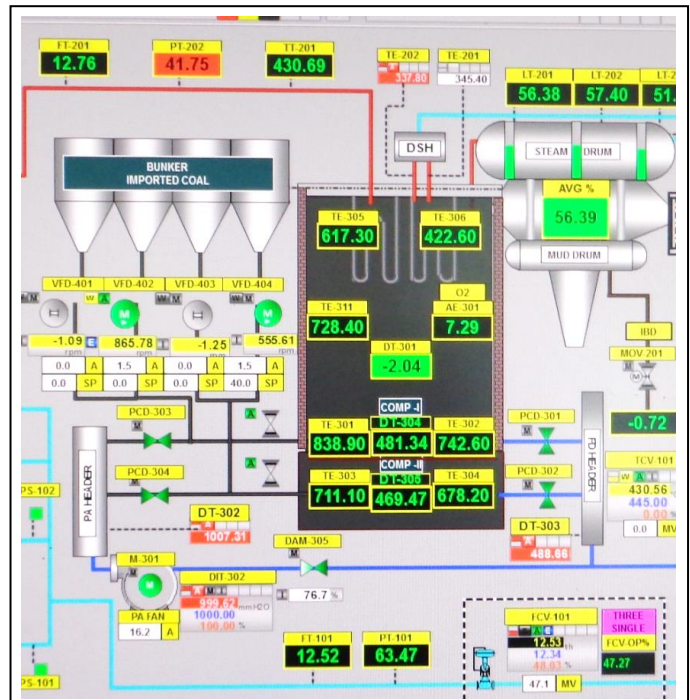


Photo 9: Different coal feed rpm & bed temp difference

temperatures & steam pressure stabilized. The oxygen level could be held constant at 4.5%. The paper GSM was at 100. Only paper machine was running. Further when the pulp section was started at around 4.00 PM, the boiler was stabilized very fast, due to deep bed operation. Operator was educated as how to change the feeder rpm and air flow

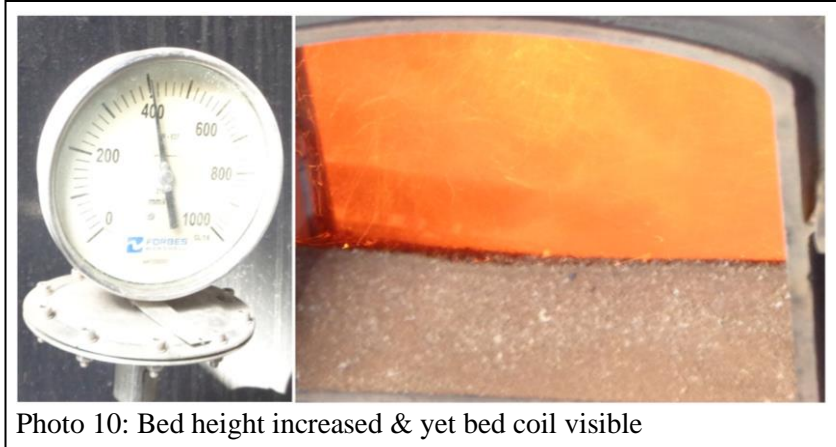


Photo 10: Bed height increased & yet bed coil visible

proportionately to load. The steam generation went to 15 – 15.8 TPH. The steam temperature was at 435 °C with steam pressure at 44 kg/cm². Operator was advised to target 46 kg/cm². The oxygen came under control. The variance in bed temperatures dropped to 27 °C & 9 °C. The proximity of thermocouples to fuel feed point & ash drain point has a say in this variance. There was minor pressure variation due to variations in steam drawl rate or GCV change of the coal mix.

7. At 6.00 PM, the GSM was changed to 120. Then also the boiler was stable. The operator was advised to how to proportionately change the air flow and coal feeder rpm. The airbox pressure was at 535 mmWC. The bed temperatures were at 860 °C – 890°C with the load was at 16.5 TPH and the oxygen was at 4%. The economiser was not steaming. The economiser water outlet temperature was at 189 °C. Drum level was stable. The FCV was at 75% open.
8. All operators learnt the advantage of the deeper bed of 425 mmWC. The bed height must be increased slowly without dropping the bed temperature excessively. The bed material gate at bed material bunker should have a hole of 50 mm only so that the feed rate is minimum & controlled. The bed inventory should be more or less constant, like boiler drum level. This is the key to stability of the combustion in AFBC / CFBC boilers. Flue gas does not transfer heat directly to bed coil. It is the bed material that transfers the heat to the bed coil. Less bed height causes erratic combustion.

CONCLUSION

The erratic coal feeding had caused disturbed circulation rate. The steam raising in 2nd compartment was upset by irregular rpm. The rpm was being kept high & constant in 1st compartment. This was a wrong practice. This promoted free board combustion in front half of the furnace. The 2nd compartment was put to thermo hydraulic cycles of steam generation due to erratic fuel feed rate. This had caused the overheating cycles of the tube. The flow was retarded frequently by the changing heat input to 2nd compartment. Hence there was a thermal fatigue. That was the reason, that this boiler had bed coil failures, whereas the failure was not experienced in the other two boiler installations.



M/S Venus energy audit system – Trouble shooting of boiler failures and operational issues. Company carries out design audit, construction audit, shut down audit and operational audit.

M/S Sri Devi engineering consultancy and agency – engaged in non-pressure parts spares supply for FBC / CFBC / PF boilers.

M/S Sri Devi boiler equipment and spares – engaged in supply of pressure part spares for all type of boilers