Bed Coil Tube Failures in AFBC Boiler – It's not always Erosion!

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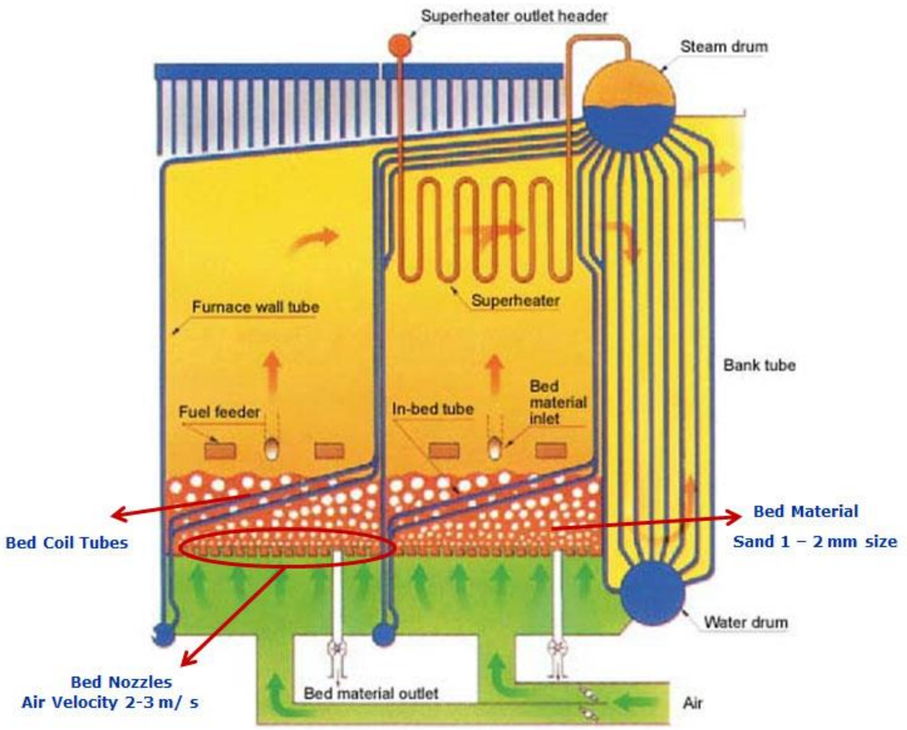
Introduction:

Bed coil tubes in AFBC Boilers are highly prone for erosion failure. If one considers the location of these tubes, it is not very difficult to understand why.



In this type of boilers, Bed Material, which is basically crushed refractory material or river sand with 2.36 mm top size, is fluidized by primary air blown through numerous nozzles at a velocity of 1 – 3 m/ s. The bed coil tubes, which are also called bed cooling tubes, are located inside the bed, where high velocity abrasive particles are in fluidized condition. The erosion is caused by the direct impingement of in-bed particles on the tube surfaces. Use of studded tubes is common practice to improve its life against erosion. In fact many boiler plants have a practice of replacing bed coil tubes every two years.

I am going to share one of my experiences with recurrent failure of AFBC Bed Coil tubes. In this case, the bed coil tubes started failing within 3 – 4 months after replacement of their studded bed coil tubes.

Photo 1: Failed Bed coil tube; Material Size & Specification: Ø 51 x 6.35 mm and SA 210 Gr. A1

There were three 80 TPH, Natural Circulation, Bi-drum, AFBC boilers at this Cement Industry CPP. They were using pet coke as primary fuel with charcoal start. Average Bed Temperature was maintained at 905°C.

Bed coil tubes of all three boilers started failing within three to four months after they have replaced the bed coil tubes with new tubes during annual shutdown. The failures were recurrent!

The visual inspection revealed severe thinning at 12 O'clock position at the failed location with no indication of external metal wastage, which is normally found with bed coil erosion.

The failed parts of the tubes were cut into two halves and gouging damage could be seen at 12 O' clock position.

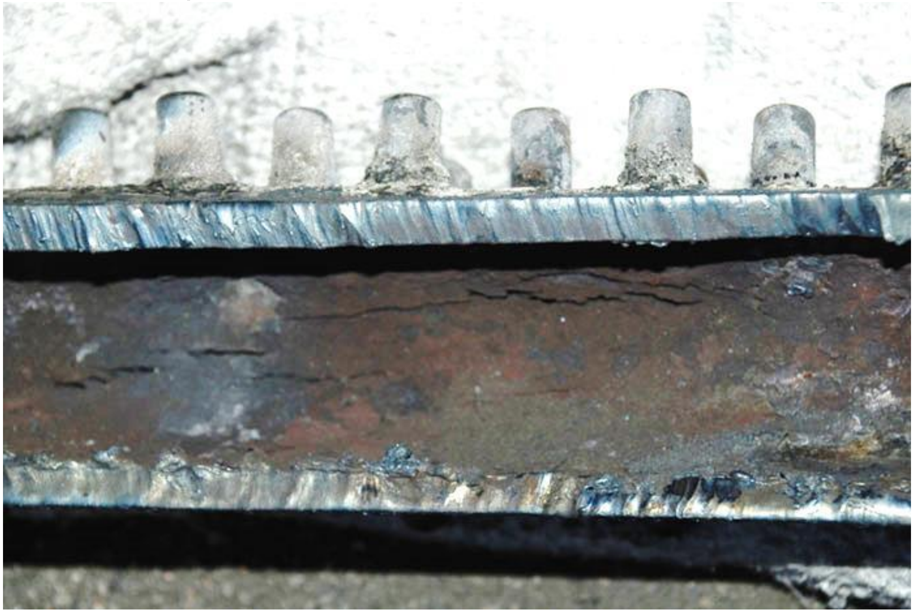
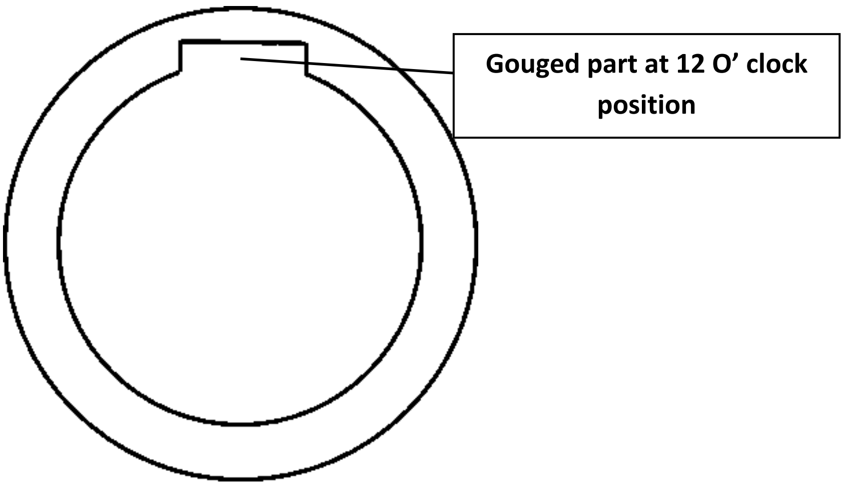


Photo2: showing the gouged part

In some places, the metal was gouged out forming a groove with regular edges as shown in the figure below.



Around the gouged part at some places, whitish deposits could be seen. A swab analysis showed these deposits to be strongly basic (pH in excess of 11) in nature.

Photo 3: deposits around gouged section

During discussion, it was noted that all three boilers are operated at nearly 25% over loading conditions. Presently drum level was maintained at 8 – 12% lower than normal level to avoid mechanical carryover. Recently they observed phosphate deposits on the turbine inlet steam valve. Residual Phosphate was also maintained at 2-3 ppm instead of required 6-8 ppm for the same reason.
Charcoal is used as startup fuel. Fuel Distribution plates were found in damaged condition. Bed Temperature was around 950^{o} C

It looked like a classic case of Caustic Gouging and it was advised to take microstructure of the failed samples to confirm the same.
Over loading along with lower drum level may have caused DNB, followed by film boiling condition. The phosphate was also kept on the lower side. Charcoal as start-up fuel also creates a sharp rise in bed temperature during start-up.

Let us now take a look into the caustic gouging problem in boiler tubes to understand how it is attributing to the failure in the boilers discussed here.

The chemical reactions involved in this type of failure mechanism are:

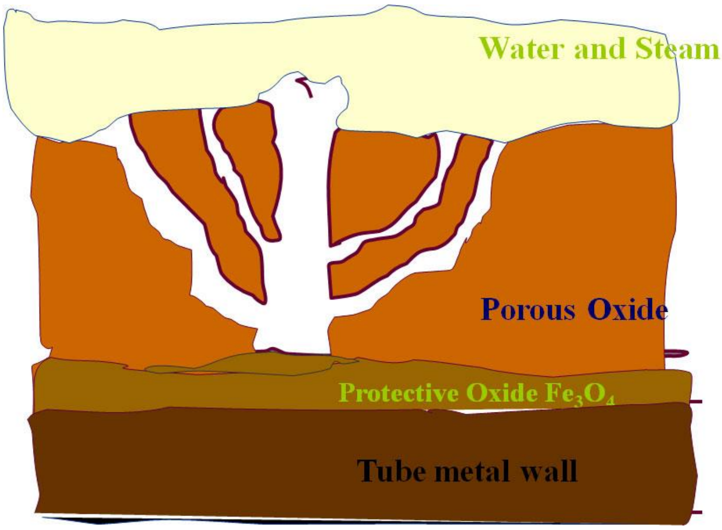
$Na_3PO_4 + H_2O \leftrightarrow Na_2HPO_4 + NaOH$
$4NaOH + Fe_3O_4 \rightarrow Na_2FeO_2 + 2NaFeO_2 + 2H_2O$
$2NaOH + Fe \rightarrow Na_2FeO_2 + 2H$

TSP (Tri Sodium Phosphate) in hot water leads to formation of caustic to increase the pH of boiler water along with some residual phosphate. Now this caustic is not present as free caustic. That happens when the boiler water pH becomes significantly high (pH > 11-12).

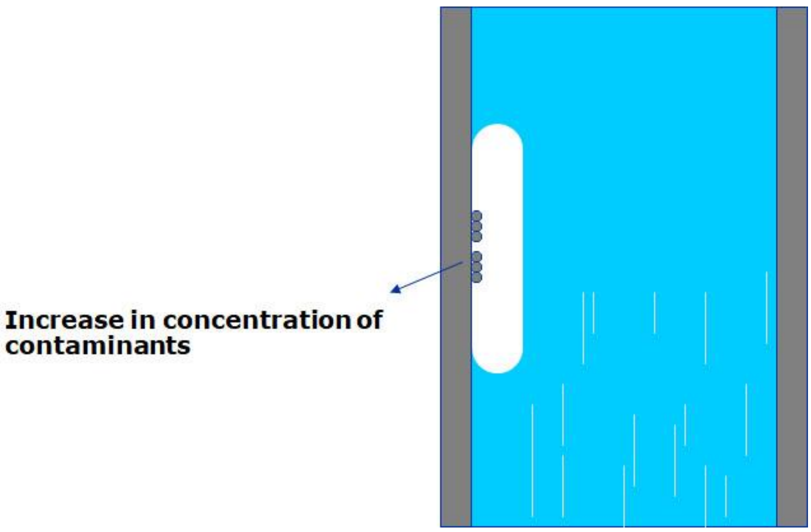
Once it is free caustic, it attacks the protective magnetite layer and removes it and then it attacks the metal. The result would be a gouging type of corrosion.

But the question is, if we are maintaining the Boiler water pH in the range of 9.4 to 9.5, then how can we get the free caustic?

The answer lies in localized concentration increasing mechanism that can be seen in the water wall tubes in certain conditions.
This may happen either below a porous metallic oxide deposit (**wick Boiling**), or below a Film Boiling condition.



The water present below a porous deposit slowly escapes through the micro-pores, which increases the concentration of various chemical parameters under the deposit. If the cation-anion is not balanced, the pH may either become very high or, very low. If it becomes highly basic, the caustic concentration will be high enough to cause caustic gouging.
Similarly, the localized concentration would increase below a **film boiling** condition (figure below) that may form in the water wall tubes due to disturbance of circulation, or, excessive heat flux.



In natural circulation boilers, the drum level and controlled heat flux on the tubes plays a very important role to maintain nucleate boiling inside the water wall tubes. It becomes even more critical during the cold start, when the quantity of steam forming in the riser tubes is less and as a result the circulation is minimum.

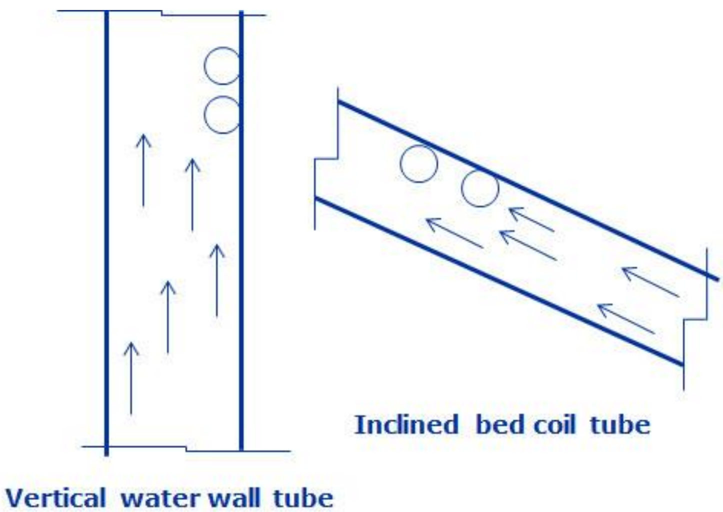
The protection against caustic gouging in such cases can be achieved by maintaining a phosphate buffer which can neutralize the caustic if concentration increases. If we take a closer look at the TSP reaction again, we would find the reaction is reversible in nature.

$$Na_3PO_4 + H_2O \leftrightarrow Na_2HPO_4 + NaOH$$

When the caustic concentration increases, the reaction reverses. We maintain the residual phosphate in boiler water so that it can neutralize the caustic to protect against caustic gouging corrosion.

What went wrong in this Boiler?

In the case I was referring, the plant was using charcoal as start-up fuel. When charcoal is used during cold start of the AFBC boilers, bed temperature shoots up to 500^{o}C within 30-45 minutes. Since the natural circulation slowly establishes as the steam load increases during cold start, this sudden increase in heat load in the bed could lead to DNB (Departure from Nucleate Boiling) and formation of steam blanketing on the tube surface. The possibilities of DNB would be more in the inclined bed coil tubes as compared to vertical water wall tubes as the natural buoyant forces on the steam bubbles act perpendicular to the direction of the flow of water through these tubes (Refer Figure below).



The film boiling would take place in the 12 O' clock position in the bed coil tube as a result.

Since the drum level significantly contributes to Natural Circulation, their decision to operate with lower than normal drum level didn't worked for them either. The reason behind mechanical carry over was not very difficult to understand in this

case. The drum separators are designed to separate the MCR quantity of steam and these boilers were overloaded by 25%!
On top of that, they had reduced the residual phosphate quantity and the available phosphate buffer was not sufficient to neutralize the caustic concentration taking place above the steam film.

Recommendations:
It was not practical to recommend either for load reduction, or, to stop using charcoal as start-up fuel. The recommendations were:

- Avoid operation with lower drum level.
- The maintenance team should thoroughly inspect the health of drum separators, especially the secondary screen separators and replace if found to be damaged.
- They should also explore the viability of installing external steam drier if they want to continue with overload operation.
- Increase the phosphate buffer to 5-6 ppm as required for their boiler.
- Check the nozzle health, straightness and health of the bottom plate to ensure even fluidization of bed.
- Replace the bed coil tubes with rifle bore tubes which might help to maintain a turbulent flow through the tubes and thus avoid DNB.