TUBE FAILURES RELATED TO COMMISSIONING & OPERATION OF NEW POWER PLANTS WITH AIR COOLED CONDENSER

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Abstract

There are many new power plants which have come up across the country in the last ten years. These units have been mostly built with air cooled condenser due to environmental considerations and due to plant locations. Several tube failures have been faced in these units due to lack of knowledge in the overall water chemistry behavior. This article is on the cases which were attended by the author and the care to be taken to avoid repetitive failures.

Water chemistry for high pressure boilers

Amongst the Industrial boiler (Drum type – Natural circulation Boiler) users, there is a good understanding the pH range to be maintained for keeping the corrosion rate at minimum. The feed water pH, boiler water pH and the condensate pH are maintained in the range of 8.5 to 10 / as per the range specified by the boiler manufacturer. The feed water / condensate pH is maintained by the use of morpholine / Ammonia / volatile amines. For boiler water, traditionally phosphate based treatment is in vogue in India. In some units all volatile treatment (AVT) has been started.

Oxygen is removed by thermal deaeration at the deaerator from the system continually. Hydrazine is generally used as a chemical scavenger to remove the left over oxygen. Of late DEHA usage is picking up as hydrazine is reported to be a carcinogen.

Dissolved solids & suspended impurities are removed at water treatment plants using pretrement plant, RO plant & DM plant. Where the water contains colloidal silica, ultra filtration is added in the water treatment stream. Colloidal silica becomes ionic only at high pressure boiling (> 45 kg/cm2 g). Always some amount of silica leaves the boiler water and reached turbine as volatile carryover. Depending on the pressure there are limits laid out on boiler water chemistry.

Units with condensate return from process plant have been equipped with condensate treatment system depending on the condensate chemistry. Condensate contamination used to occur at power plants equipped with water cooled condenser. These units were fitted with online cation conductivity monitor so that the contamination could be detected immediately on occurrence. Unit will be stopped immediately as the organics in cooling water brings down the boiler water pH rapidly due to acid formation. The residual phosphate maintenance programs used to take care of the cooling water breaching to some extent.

Many thought units with air cooled condensers are safer to operate as it is closed system without cooling water contamination. First time I was called by two customers saying that the boiler water silica was uncontrollable for more than a week since turbine was rolled. I explained it had to do with the ACC. I advised to them to return the condensate back to water treatment plant. This suggestion was of help to them.

CASE STUDY 1: REPEATED WATER WALL TUBE FAILURE IN A 250 TPH CFBC BOILER

This was newly commissioned unit with a Chinese boiler. The customer sought our diagnostic service to solve their repetitive waterwall tube failure in the installation. The boiler manufacturer had given up saying that there are many units operating in their country. There were some urgent modifications carried out in the downcomer & riser arrangements as the failures were always in some sections only. The failed tubes showed the sign of rapid overheating and burst that appeared as fish-mouth. See photo 5. During the diagnosis, there were so many parameters which had led to the failures.

The first CFBC boiler was commissioned in the month of October 2009. The power plant had been in operation for a total period of 326 hrs. Within this period, there had been 34 stoppages. Out of these stoppages, three tube failures were due to the WW tube bursts experienced in the LHS & RHS panels at rear corner & two adjacent tubes at the upper part of furnace. The tube failures had been 200 to 400 mm below the refractory lining near the furnace outlet. The tubes burst show the sudden overheating. The tubes have burst due to sudden loss of circulation / Departure from nucleate boiling or steam blanketing. The failed tubes did not exhibit long term overheating.

The boiler was under shut down at the time of visit. As requested the steam drum was opened and offered for inspection. The boiler drum exhibited the cause for failure. See the photos with explanations in annexure 1.

Boiler water & condensate chemistry problem

The steam drum was exhibiting low pH corrosion and there was no magnetite layer formation of internal surface. There was no distinct water to steam interface. The steam purifying driers also showed the reddish appearance confirming the foaming of the boiler water. See photos 1 - 3. A good drum appears as in photo 4 (of course after regular operation).

It was learnt that during the entire operating period the best silica level in condensate was only 0.07 ppm. The condensate was always seen with high silica levels. See table below:

Table 1: conductivity & silica levels in return condensate							
Period of operation		18/9-21/9	25/9 -28/9	1/10 - 5/10	15/10 - 19/10	2/11 to 4/11	
Conductivity	µs/cm	25.5 to 8.3	8.8 to 10.5	4.2 to 6.1	5.2 to 6.9	9.7 to 11.4	
Silica	ppm	0.31 to 0.42	1.67 to 0.3	0.13 to 0.41	0.07 to 0.25	0.25 to 0.35	

There had been very high blow down rate done to limit the silica in boiler water. Under this circumstance the phosphate dosing had been raised. But simultaneously high blow down was maintained. This should have led to low pH levels in boiler water. It was confirmed that the blow down water was reddish. However the boiler water phosphate and pH were high confirming that the boiler water was alkaline. This could have been due to presence of foaming or due to drum internal arrangement. Though the boiler water chemistry seems OK, the boiler internal surface did not say so. A wipe off shows the drum surface was red. There was no grey surface at water space or steam space. The following were the boiler water analysis data.

Table 2: pH & silica values in boiler water			
The pH values	The PO4 values		
9.15,9.9,9.9,9.5,9.56,9.64,9.65	22.4,8.15,10.4,4.6,10.4,3.8,5.5,7.9,9.8,4.5		

Drum internal arrangement

There is a possibility of stirring effect by the feed water distributor pipe. See photograph 9 & 10. It is the normal practice to locate the chemical pipe in such way that the feed water carries the phosphate chemical to the downcomers. In steam drum internal layout, the blow down pipe should be arranged in such a way that the high TDS return water is taken out without mixing any fresh water / chemical. In the present drum internal arrangement the holes in feed distributor is 30 deg upward to horizontal. The two distribution pipes can stir up the chemical and cause a sampling error. It was advised to rotate the feed distributor pipe so that the water ejects downwards. The chemical pipe can be connected to feed distributor pipe close to inlet point in the drum. This will help in proper mixing with feed water.

Proper pre-commissioning care for start up of the unit

Air cooled condenser has large heating surface as compared to boiler. Air cooled condensers are not chemically cleaned during pre-commissioning. It generates corrosion product during every start up. The first steam that enters the ACC is generally of low pH it starts removing the loosely held corroded iron. The corrosion product due to oxygen exposures also would come in to the condensate. The contaminated condensate chokes up the strainers at CEP inlet. Also the BFP strainers will be choked as the mesh opening is lesser than that of the CEP. It is reported that the strainers exhibit reddish fine particles. This can increase the conductivity and silica depending on the internal surface of the ACC tubes. This had forced the high blow down rate from the boiler. See the rate of blow down had been as high as 7.7 to 9.52 %. It was confirmed that colloidal silica was absent in the feed water. Hence the source of contamination can be from ACC. There was lot of mismatch in boiler water chemical consumption.

			cond 1	Condn 2
Current steam generation capacity of boiler	kg/h	=	250000	250000
Conducitvity of feed water		=	4	7.9
Conductivity in Boiler water	ppm	=	46	110.3
Percentage blow down	%	=	100 x 4 /(46 - 4)	100 x 7.9 /(110.3 - 7.9)
	%	=	9.52	7.71
Actual blow down rate		=	250000 x 9.52 / 100	250000 x 7.71 / 100
	kg/h	=	23800	19275
Phosphate ppm maintained in boiler water	ppm	=	10	10
Loss of phosphate in blow down water	g/hr	=	23800 x 10 / 1000	19275 x 10 / 1000
		=	238	192.75
Loss of TSP in blow down water		=	238 x 4	192.75 x 4
	kg/h	=	952	771
Tri sodium phosphate consumption per day	kg/d	=	952 x 24 / 1000	771 x 24 / 1000
	kg/d	=	22.8	18.5
Indion 2574 used per day - actual	kg/d	=	5.0	5.0
Purity of TSP	%	=	75.0	75.0
Actual TSP addition	kg/d	=	3.75	3.75

The TSP consumption should have been 18 to 23 kg instead of 5 kg as per log sheet. Usually the chemical consumption will be more from the estimated value due to low purity levels. There is no flushing arrangement for ACC in the condensate piping system. This is a must as per experience by others as well.

Frequent tripping & ACC being off line

There had been as high as 34 tripping of the power plant. During this tripping the ACC went off line. Every time the ACC was exposed to air and it could corrode. When the condensate was taken without treatment it could contaminate the boiler water with suspended & dissolved impurities. This made the boiler water dirty leaving the possibilities of choking the bottom drain valves. The high blow down requirements and boiler drain valve choking confirmed this. The hot box of the boiler led to choking of the drain / bottom supply pipes as the dust would settle to bottom most point.

Physical arrangement of downcomers & riser

The distributing pipes are tapped off from the main downcomer and connected to all four walls. The failures had been in the last five tubes at the ESP side on both left & right side panels. The distributing pipes to this section of the boiler are taken from the bottom most point of the main downcomer. See photograph 7 & 8. The front & rear waterwall panels (226 tubes) are fed by 18 distributing pipes. The left & right side waterwall panels (170 tubes) are fed by 14 distributing pipes. The rear waterwall tubes have lot of bends as compared to the side waterwall panels. When there is undersized downcomers, the failures will be experienced at all water wall tubes and the worst affected will be the rear waterwall panel tubes. Since the tubes of left & right side waterwall panels have failed, the problem is simply related to starvation only in the extreme ends. Looking in to symmetry of the boiler about the centre, we can understand that there is a problem only in the lowest distributing pipe. It is very much possible that the water flowing is disrupted when there is as stoppage and restart. On stoppage of boiler / load reduction / on filling, the corrosion products tend to accumulate at bottom most pipes only. This can retard the flow rate to the extreme tubes of the LHS & RHS panel tubes.

Accumulation of dirt in low velocity tubes

As such the corner tubes can have less circulation as there will be less heat pick up. Dirt build-up / concentration is usually more in such tubes. This can cause overheating failures as the cooling may be retarded.

Failure to do low pressure blow down during commissioning

During commissioning of the new boiler, Low pressure blow downs are done with fire off. This helps in attaining good water chemistry in a short time. Moreover when there is a mechanism of dirt generation in the boiler or even after the tube replacement job, the boiler calls for a low pressure blow down. It is learnt that this was not done.

Storage post hydrotest stage

It was learnt that the water used for hydrotest was left inside the boiler for a long duration. This is not proper. During long outages, the boiler needs preservation against corrosion. The water should be completely removed and hot air should be admitted in the boiler. This is the best practice followed. See photograph 11 in annexure 1. Simple alternate method is to place a tray full of silica gel / lime inside the drum. This will have to be followed at TG exhaust & condensate storage tank also so that the ACC will be dry. Failure to preserve the boiler & ACC will accumulate dirt inside the boiler and lead to plugging of evaporative circuits.

Hand hole pipe & drain at main downcomer

At present there is no adequately sized hand hole pipe system in any header. Hand holes pipes help to clean the system after the alkali boil out in a better manner. In this boiler the main downcomers act as trap. In some boilers the bottom ring headers collect the dirt. It is safer this way. The drain pipe of 50 nb is directly fitted to end plate. Further the drain valve is of 25 nb and is of globe type. It is difficult to de-choke this valve even by tapping. It is learnt that the valves have got choked often. This confirmed the presence of sufficient amount of corrosion products. The drain arrangement needs to be modified. See the better arrangement in photo 12. This arrangement was recommended at wing-wall downcomers also.

Globe or gate type valves for drains

It is advised to provide 40 nb / 50 nb drain values of gate type. Gate type values help in easy removal of blockages. When the boiler is restarted after the repair work or annual overhauling, the water should be flushed out from the boiler by keeping the drain value open.

Piping system after the drain valves

The drain piping from the main downcomer is connected to blow down tank. Unfortunately the drain piping is with a U loop. As long as the boiler is under pressure, the water may flow to tank. When the pressure is less, the last run of dirty water will trap in this U loop. It is a good engineering practice to slope the drain lines towards the final outlet point. It was suggested to have an alternate direct drain to trench.

A Quick check on circulation velocity

This boiler has two main downcomers of 350 nb, feeding the water for the fours side waterwall panels. It was informed that the CR ratio is 6.7. This will have a velocity of 3.2 m/s in main downcomers. The distributing pipes are of 125 nb pipes. The water velocity in these pipes is 2.1 m/s. The steam water mixture velocity in risers will be 3.95 m/s. There is no under-sizing of downcomers or risers.

Filling arrangement

For hydrotest purpose, the boiler must be first filled from the SH side to prevent any dirt going to the superheater coils. Otherwise we may experience tube failure in superheater coils.

Lessons

The lack of provisions for proper cleaning during pre-commissioning & operational cleaning and ACC debris ingress had led to the multiple tube failures.

CASE STUDY 2 : REPETITIVE FURNACE WALL TUBE FAILURE IN A 85 TPH CFBC UNIT

The plant was commissioned during November 2007. The boiler parameters are 85TPH, 88 kg/cm2g and 515 deg C. The boiler had several stoppages on account of bed ash cooler design, cyclone refractory break down, air nozzle failures. The boiler started developing leakages in combustor wall

during the year 2009 & 2010. This was mistaken for erosion related failure. Thickness was built up during every failure and the unit was put on line again for 3 -4 times. In March 2010, the tubes developed long cracks. The new power plant GM had resorted to tube removal & inspection. As soon as he noticed that the tubes were being corroded inside with gouging marks, he arranged for detailed investigation.

Appearance of failed tubes & boiler drum

- 1. The failed tubes had gouging marks. See photographs 13 & 21.
- 2. At some location the tubes had hydrogen cracks. This can be seen in photographs 14 & 21
- 3. Tubes were seen to have deposits.
- 4. The failure was above kink zone. This was a high heat flux area.
- 5. Drum inspection revealed boiler tube corrosion / dumping of corrosion products from elsewhere. Loose powdery material was seen accumulated inside the drum. See photo 15 & 16. The same would be present as porous deposits in high heat flux zone and as well as low velocity circuits. Tubes inspected insitu confirmed this. See photograph 18.
- 6. One of the bottom headers was cut & seen. It showed alarmingly high level of corroded boiler tubes waste. See photograph 17.

Failure mechanism

The kind of gouging marks & cracks prove that there had been under-deposit corrosion taking place. There were several causes which came to light when the investigation was completed.

Causes & prevention

- 1. Since the boiler was not running continuously, it generated rust during every start. It was necessary to give low pressure blown down at a pressure of 5 kg/cm2 during start up. But this was never done.
- 2. Low pressure blow down should be practiced during every shut down to get rid of loose corrosion products from the boiler. This was not done at all.
- 3. Air cooled condenser generates corrosion product whenever it is offline. Hence the start up condensate should be dumped to WTP or to drain. This will avoid dumping of corrosion products to boiler. It is advised to monitor the condensate chemistry every half an hour for turbidity, pH and iron whenever ACC is taken in to circuit.
- 4. ACC Off line preservation can be practiced by using silica gel / VCI pellets / or by circulating hot air.
- 5. ACC being very large, appropriate amine should be dosed for pH control. To check whether there is proper protection with amine or not, it is advised to monitor dissolved iron on a continuous basis. As soon as the plant is shut any time, Condensate tank must be inspected for reddish color. If it is reddish instead of dark grey, it means the amine needs to be a mix to cover short & long distances. It is advised to use morpholine & cyclohexylamine mix for better results. Hydrazine use as Oxygen scavenger shall be stopped. Instead DEHA shall be selected. The breakdown of DEHA is minimal as compared to hydrazine. Ammonia contributes to bulk water pH but it does not offer complete protection in the process of condensation. This is because ammonia tries to be in vapor until the entire condensate is formed. ACC tubes being very long, the upper part of ACC tube is not protected with the right pH condensate.
- 6. The boiler is designed with a water cooled cyclone. By virtue of differential heat flux, there may

not have ideal uniform circulation velocity as compared to main furnace tubes. It is likely that the corrosion rates accelerate when there is ingress of corrosion products. See photograph 19.

- The boiler was being operated for IBD ceremoniously. This is not correct. This upsets the PO₄ & pH in boiler water. Chemical dosing rate was seen to fluctuate. The PO₄ was seen to range from 12 to 24 ppm.
- 8. Ideally for high pressure boilers, PO_4 should be limited to 3 to 5 ppm. Since there is no contamination possibility from cooling water, this level is sufficient. In the sense a certain reserve of OH is required to maintain the magnetite formation. Free hydroxide alkalinity shall be limited to 1-2 ppm.
- 9. In order to maintain pH limiting the PO₄, it is advised to mix Tri sodium phosphate & Disodium phosphate.
- 10. Check the phosphate chemical for chlorides & silica. Only lab grade Phosphate is recommended. Chloride ingress can drop the boiler water pH. This could have taken place sometime depending on the lot.
- 11. The under deposit corrosion mechanism takes place mostly at high heat flux area, which is about 5 m above kink area. It is recommended to replace the waterwall from the weld joint at kink area. There shall not be any weld joint within the 5 m distance above the kink. Preferential erosion can thus be avoided.
- 12. It is seen that the fly ash & loop seal ash is not being analyzed for size distribution. In order to distribute the heat flux across the furnace, the fines (> 100 microns) are to be retained in the furnace. It is advised to procure sieve shaker with finer mesh sizes. Regular analysis is recommended.
- 13. The amount of lean bed height in the furnace is important for heat transfer. There has to be two draft transmitters just above kink. We can get to know the presence of adequate lean bed for heat transfer in upper furnace. Insufficient dust in furnace can cause differential heat pick up & differential erosion.
- 14. In this boiler, the rear wall is provided with complete refractory. This can cause differential steam generation as compared to other three waterwalls. The rear wall should have been with a separate outlet header (instead of a common header for front & rear walls) for better circulation. This is not to say that common header is the cause for the failure. But bad boiler water (with corrosion products- either generated or transported to boiler) will lead to accelerated corrosion.
- 15. It was learnt that the spectrometer was not available for a long period. It was possible that the water chemistry went hay where.
- 16. It is highly possible that out of the numerous idle periods, proper preservation procedures have not been adopted for boiler. Since the boiler is fully drainable, the water must be fully drained and kept dry. Silica gel / VCL pellets can be placed inside the steam drum to prevent moisture related corrosion. To stop corrosion the air should not have water vapor. Hydrated lime shall also do the job. The same can be followed for ACC & steam duct.
- 17. The ACC condensate must be tested regularly for the turbidity, dissolved iron, total suspended solids and pH.
- 18. It is observed that the chemists came in general shift only. The $pH PO_4$ maintenance in boiler water is taken lightly. The 2P-M value shall be 1-2 ppm in boiler water.
- 19. It is learnt that the strainers of HP chemical dosing pumps do get choked often. The matter is taken lightly. The pump should be working on a continuous basis. The pump is to be relocated to ensure the strainer does not get choked.

- 20. On drum internal inspection, it was noticed that the downcomers for cyclone inlet duct & riser connections at steam drum are located so close to each other. See photo 21. This may allow steam to enter in to the downcomer. This may be checked in this installation. If the arrangement is same, it is advisable to provide an extension pipe to riser stub up to NWL. A canopy can be provided at the extension pipe to avoid steam throw direct to the steam driers.
- 21. Annual inspection of boiler must be focused to ensure the boiler is in good health.
 - a. Steam drum should be inspected and photographs should be taken. The surface of the boiler drum should be grey in color. Reddish color indicates the variation in boiler water pH.
 - b. Bottom header hand hole plates should be cut & inspected.
 - c. Condensate tank shall be inspected for corrosion products and shall be cleaned.
 - d. The deaerator shall be inspected for debris from ACC.
 - e. Whenever the CEP strainer is choked, analyze the choked material.
 - f. Depending on the corrosion rate of ACC, condensation filtration and / or polishing system is recommended. This decision is based on the powdery material collection from the CST.

Conclusions

A chemical cleaning by EDTA was recommended and followed by a hydrotest at 1.25 times the design pressure to ascertain the minimum thickness is available for service. A thickness measurement conducted proved to be a waste. The boiler showed up many leakages before the unit could be put back on line.

CASE 3: TUBE FAILURES IN CFBC & AFBC BOILERS AT SAME INSTALLATION

When the first unit was commissioned, the Power plant head spoke to me about the high rise in silica levels in boiler water. IT was perplexing how the silica in boiler water was going up thought WTP was equipped with Ultra-filtration system. As the silica ingress was heavy from the ACC, I advised to return the condensate back to water treatment plant. Accordingly the condensate was rejected till the condensate was satisfactory. Subsequent units were commissioned accordingly. The first boiler that was commissioned was the AFBC boiler. Subsequently the second AFBC boiler & CFBC boiler were commissioned. At that time phosphate based treatment was practiced. The PO4 level was kept at 2-4 ppm. The boiler pressure being 88 kg/cm2, this was advised to avoid caustic gouging. The bed tubes of the AFBC boiler was of plain tubes. In spite of proper care, the unit suffered caustic gouging within a year of commissioning. Rifle bore tubes remove the intermittent flow of the steam inside the low sloped tubes. The cause for caustic gouging was due to poor circulation system design and the over loading of the boiler. But this client was interested in retaining the plain tube bed coils due to high cost of the rifle bore tubes.

However, AVT based internal water treatment was selected to avoid caustic gouging. The phosphate dosing was stopped completely. The unit was on hydrazine treatment as well for oxygen removal. This went on nearly for two years. Two years later, there were tube failures in all three boilers.

Water wall crack in CFBC boiler

The failed tube can be seen in photo 22 & 23. The tube had a long crack along the high heat flux area. The tube had failed just above the refractory lined furnace. There was a tube failure reported in

water wall area of CFBC boiler. The tube showed the presence of the deposits.

Bed tube crack in AFBC boiler1

The failed tube can be seen in photo 25 & 26. The tube was blown close to the bend and a weld joint. The tube showed the presence of the deposits. See photo 27.

Bed tube crack in AFBC boiler 2

The failed tube can be seen in photo 29. The tube shows the long cracks and the deposits inside the tube. But the drum is not with deposits, but with loose corrosion products as can be seen in photo 31.

Causes

In this case too, there were numerous reasons for deposit generation and accumulation inside the evaporative circuit. They are summarized below.

- 1. Porous deposits inside inform that the condensate chemistry was not OK.
- 2. Whenever the ACC goes off the circuit, it undergoes corrosion due to oxygen. On restarting the corrosion products are dumped to boiler. The corrosion products circulate within the boiler evaporative circuit leading accelerated corrosion by way of further corrosion of boiler tubes.
- 3. In normal running itself, the ACC may corrode due to inadequate chemical dosage practices and lead to dumping of iron in to the boiler circuit. The boiler was not inspected properly during shut down. The color of steam drum being satisfactory, the doubt on health of the boiler did not arise. Photo 31 showed a good drum but with fine suspended solids. Photo 30 is the inside picture of CST which explains the corrosion of ACC tubes.
- 4. Iron oxide deposits at high heat flux area / low velocity circuits. This can upset the water chemistry locally and lead to further corrosion.
- 5. High blow down which may be practiced during start up for silica control, may deplete the boiler water chemical leading to acidic regime.
- 6. Deposits are bound to generate whenever the boiler goes off line. On restarting the boiler needs low pressure blow down at all bottom drains to discard the oxides out of the system. The blow down is to be done with fire put off.
- 7. During annual inspection, drum & bottom most headers, condensate tank have to be inspected to know the health of metal and to decide the chemical dosage modifications. Possibly this was not addressed during annual shut down. The condensate tank which was inspected later after the failures, showed signs of ACC corrosion. See photo 30. Photo 31 explains the condition of good boiler water chemistry. But the iron oxides transported from ACC are seen inside drum.
- 8. Alkali boil out after replacement of bed tubes have to be followed with boiler flushing from top header hand holes in order to remove the sludges. Leaving the sludges within the system will lead to deposit related corrosion.
- 9. Since the CFBC cyclone & Cyclone inlet ducts are of water cooled design, it would act as sites for deposition of corrosion products due to low flow.
- 10. In CFBC, the cyclone inlet duct is with horizontal tubes, which can trap dirt and lead to sites for deterioration of metal surface due to steam blanketing.
- 11. In furnace rear wall the tubes are arranged horizontally. This can lead to steam blanketing and chemical concentration. Chemical concentration would dissolve metal at a faster rate.
- 12. In CFBC combining the front wall & rear wall at a common header was not a good idea from

circulation point of view.

- 13. The Hydrazine used for oxygen scavenger is breaking down to ammonia and providing the required pH in condensate. This is not OK. Oxygen scavenger shall be done through DEHA. Neutralizing amines shall be used for boosting the condensate pH. A mix of morpholine & cyclohexylamine shall be used for achieving the least particulate iron / dissolved iron.
- 14. To stop the dumping of ACC corrosion products filters shall be installed. Or else the condensate shall be dumped to water treatment plant unless the turbidity is normal.
- 15. Requirement of continuous filtration system has to be decided based on condensate filter test results. If the condensate filter test proves corrosion, then on line filtration is required.
- 16. In AFBC boiler, the front wall & rear walls are of low velocity circuits and hence can lead to aggravation of deposit related damage.

Conclusions

Several measures were suggested to be followed immediately to remove the deposits.

- 1. Physical inspection of headers would inform the extent of corrosion products inside the boiler. Sample tube removal at high heat flux areas would also inform of the deposits.
- 2. Water flushing through all tubes from top header to bottom header is advised. Water flushing at bed coil outer header is also advised. This is to reduce the loose deposits and to prepare the boiler for a chemical cleaning.
- 3. For iron oxides deposit removal EDTA (ethylene diamine tetra acetic acid) is recommended. It is advised to carry out a trial at laboratory for the dissolving of the iron oxide scale. It is desirable to work with a chemical vendor for this purpose. The failed bed coil bend with deposit shall be weighed & photographed initially before the chemical cleaning is done. The concentration of chemicals requirement can be known. In fact when the chemical is purchased, its effectiveness must be tried on tube sample before it is administered on the boiler.
- 4. The hydrazine is known to break down at high pressure inside the drum and generates ammonia. This was seen in another plant when the condensate tank & deaerator were inspected. It was advised to check the condensate tank for corrosion at the next shut down. And this was done and the photograph was sent later. The photo confirmed the corrosion of ACC.
- 5. It is advised to stop using hydrazine as oxygen scavenger. DEHA shall be used instead. For pH boosting of condensate morpholine & cyclohexylamine is recommended. It is advised to monitor particulate iron by filtration of large quantity of sample to understand the corrosion rate of ACC. Based on this decision has to be taken to install condensate filtration system / polishing system.
- 6. It was advised to take up with AVT supplier with respect to break down of chemical in deposit affected zone. It may be possible that it had led to hydrogen crack at deposit sites. Whether the bulk water is going to be alkaline / acidic, under deposit corrosion would result in caustic attack or hydrogen attack. Hence deposits have to be prevented or removed regularly.
- 7. Low pressure blow down has to be adopted whenever possible. It is necessary that all drains (including drains of cyclone inlet duct & cyclone inlet header.
- 8. Whenever the turbine is restarted, the ACC condensate has to be discarded until the turbidity is normal. If ACC condensate is to be used all time, we have to install condensate filtration & polishing system.
- 9. Annual / once in two years, chemical cleaning of boilers would have to be adopted depending on the deposition levels.
- 10. In CFBC boiler deposition levels have to be assessed by cutting tube samples at furnace (high

heat flux area), cross over duct (horizontal tube) and cyclone tube where tube is horizontal. In AFBC boiler tube sample has to be at bed coils & above the fuel feed point.

11. ACC can be preserved by means of VCI pellets or by hot air circulation. The hot air fan has to be hooked to condensate storage tank so that the air would fill the ACC & come out from turbine end. It may just need a 5 deg C rise to ambient to keep the ACC dry of moisture.

Corrosion mechanism explained

Under deposit corrosion begins with a deposit. The source can be unremoved mill scale, corrosion products from condensate or contaminations due to plant upsets / stoppages. Regardless of source, the deposit creates an area beneath it that is chemically different from bulk water. The process generates a corrosion cell.

Detailed corrosion mechanism

Formation of magnetite layer

The control of corrosion in boiler environment is based on maintaining conditions which enhance passive film formation. Magnetite, Fe_3O_4 is the preferred high temperature iron oxide form. Well crystallized (unhydrated) magnetite forms a dense layer resulting in excellent passivation. The formation of magnetite takes place as shown below.

Fe ²⁺	Ferrous ion		
Fe ³⁺	Ferric Ion		
FeO Ferrous oxide – Iron II oxide			
Fe ₂ O ₃	Ferric oxide – Iron III oxide		
Fe ₃ O ₄ Ferrous ferric oxide – Iron II, III oxide			
FeOH	Iron II hydroxide		
FeO(OH) Iron II oxide hydroxide			
Fe(OI	H) ₃ Iron III hydroxide		

 $\begin{array}{ll} (Reaction -1) & Fe + 2H_2O <-> Fe^{+2} + 2OH^- + H_2 \\ (Reaction -2) & Fe^{+2} + 2OH^- <-> Fe (OH)_2 \\ (Reaction -3) & 3Fe (OH)_2 <-> Fe_3O_4 + 2H_2O + H_2 \end{array}$

It is seen from reaction 2, that the hydroxyl ions are to help in continuous formation of $Fe(OH)_2$ – that is soluble iron II oxide. Fe_3O_4 forms over the inner surface of tube offering a continuous protection. On the whole it is a passivation process is basically due to an active surface of Fe being corroded to a relatively inactive state of Fe_3O_4 .

Hydrogen attack

In reaction 1, the hydrogen which is released continuously has to be consumed by the free OH ions present in alkaline water. But under the deposits, the flushing action is absent. The hydrogen that is released vide reaction 1 is forced to back to travel through pearlite grains. Here the carbon reacts with hydrogen to form methane distorting the grains and creating voids or fissures. The heat facilitates the diffusion of hydrogen through the grain boundaries. Case study 3 is exclusively a case of hydrogen attack since the boiler was on AVT.

(Reaction 4) - $2H_2$ + Fe3C (pearlite) \rightarrow 3Fe + CH₄ \uparrow

Caustic attack

When the bulk water contains high amount of free hydroxides, they can concentrate under deposit

leading to caustic gouging. This is nothing but high alkaline corrosion. That is formation of magnetite layer is retarded. Case study 2 is a case of high & low phosphate levels in boiler water.

(Reaction 5) - Fe (OH)₂ +OH⁻ <-> Fe(OH)₃ + HFeO₂ + H₂O (Reaction 6) - Fe (OH)₂ +2OH⁻ <-> Fe(OH)₄ <-> FeO₂ + 2H₂O

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Photo 1: The drum internal showing the low pH situation. There can be iron loading from ACC during pre-commissioning. Usually if the corrosion products are transported from the pre-boiler circuit, the dirt appears dark brown but the boiler surface will show gray surface. If the corrosion products are generated within the boiler circuit, then the grey surface will be absent.



Photo 2: The downcomer inlet is provided with vortex breaker. This exhibits the flow of reddish boiler water.



Photo 3: The screen drier showing the foaming inside the drum due to iron in boiler water. The magnetite layer is not seen even in steam space. This is an indication of deviation of boiler water pH.



Photo 4: This is the color of the steam drum when the boiler water pH & PO4 are properly maintained



Photo 5: Tube burst showing instantaneous overheating- This is failure due to steam blanketing which is the result of disrupted flow in the tube.



Photo 6: The main downcomer is not provided with a dirt trap / hand hole plate. The drain size is small. It was informed that the drain was choked during boiler operation. On every hot box up, the floating dirt would settle at this header end cap.



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In the last several years, the use of Air Cooled Condensers and Surface Condensers has become more prevalent. The units are particularly attractive for new power plant installations where the supply of water to the plant is limited and where there are restrictions on the disposal of blowdown water from both the boilers and cooling towers.

ACC equipped plants pose some unique challenges during the plant start-up. Specifically, due to the lower heat transfer coefficients typical for air cooled condensing surfaces compared to a water cooled condenser, the ACC must have considerably more heat transfer surface area compared to a water cooled condenser. Furthermore, an ACC is constructed of mild steel rather than titanium or brass, and the mild steel represents a significant source of contamination that must be flushed from the system during initial operations.



BES&T is in the process of patenting the SigmaCommissioning[™] process, which allows for a traditional steam blow, exhausting to the ACC's, and cleaning these vital components at the same time. Some of the benefits of this process include:



- Reduced fuel usage/cost during steam blow - the quality of condensate that returns from the ACC improves to the extent that most can be recycled to the HRSG's w/minimal treatment
- Reduced fuel cost during plant performance run - formulated chemistry is added to exhaust steam to enhance the removal of silica from the ACC metal surfaces avoiding extended operation in bypass mode
- Reduced schedule less time for performance, restoration and clean up of chemistry can reduce schedule by 10-14 days
- Reduced temporary water cost little if any temporary treatment equipment from vendors is required
- Reduced GT starts can be completed with as few as three gas turbine starts.

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Note 1: The above is a feedback from a commissioning service company. My feedback on Air cooled condenser commissioning at two sites was the same as informed to you. The ACC needs proper hook up to avoid dumping dirt to boiler circuit. The BFP choking is still experienced even after three months of commissioning.



Photo 7: The present downcomer arrangement. The bottom most supply pipes feed the extreme WW tubes in the LHS & RHS. If this is choked then the tubes may starve.



Photo 8: Even the front & rear waterwall tubes are fed by the bottom most supply pipes. But the connection is at middle. The remaining supply pipes would ensure supply.



Photo 9: The feed water distributor is arranged in such a way that the water outlet holes are facing 30 deg up to horizontal. This arrangement can stir up the drum with phosphate and lead to high phosphate in blow down. Then the boiler water chemistry will be different from what the sample indicates. It is advised to direct the holes downwards. Though the boiler water pH and PO4 were OK as per report, the drum internal surface indicates low pH. The chemical dosing line has to be connected to feed distributor itself.



Photo 10: Arrangement of feed distributor with holes facing upwards. This could stir up the chemical leading to wrong diagnosis.



Photo 11: Hot air circulation in boiler during idle period.



Photo 12: Good engineering practice by another boiler maker. The main downcomer has a hand hole & a drain valve taken above the end cover.



Photo 13: The failed tube is seen with long crack. The tube is blown out by hydrogen attack. The pits indicate the under deposit corrosion situations.



Photo 14: The failed tubes from furnace side. The tubes are vertically oriented in position and tube crack is along the crown. The cracks were seen above the bottom refractory zone, where the heat flux is highest.



Photo 15: The drum internals show presence of high level of corrosion products inside the boiler. Widely varying pH conditions must have taken place.



Photo 16: The presence of loose circulating material can be seen at the downcomer. These powdery materials can deposit at high heat flux zones & at low flow Cyclone tubes / cyclone inlet duct that is water cooled.



Photo 17: The high level of corrosion products which should have generated due to poor storage practices, low pH situations and under deposit corrosion products.



Photo 18: The tube showing the present of deposits and the corrosion pits.



Photo 19: There are three circulation circuits, namely furnace wall, cyclone connecting duct and the cyclone. Based on the heat flux & by the complicated tube bends, slope of tubes, any contaminants present would tend to accumulate at low flow circuits & accelerate corrosion. Boiler design also should address well circulated tubes. Refractory lining the entire rear wall can lead to poor circulation. Positioning a common header for both rear & front wall was not a good idea for boiler with more steam – low circulation ratio.



Photo 20: The positioning of downcomer & riser so close to each other can retard the flow in the circuit due to steam entrapment.



Photo 21: More furnace tubes exhibit the presence of the corrosion products and the under deposit corrosion mechanism.



Photo 22: This is the tube that failed in high heat flux area in furnace tube of CFBC boiler. The failed location was about 2 m above kink zone.



Photo 23: The outer surface shows thick edged crack which is typical of hydrogen crack. This is not an overheating failure by any other strongly adherent deposits. It is a propagation of hydrogen crack under the deposits and at high heat flux area.



Photo 24: The inside of wall tube in CFBC shows the sign of deposits in water.



Photo 25: The AFBC boiler tube (unit 3) is showing deposition of corrosion products and the crack originated due to hydrogen. The tube is blown out.



Photo 26: The site for deposit is close to weld joint ahead. Surface discontinuity offers sites for deposition of corrosion products. This tube is from AFBC boiler.



Photo 27: Another bed coil tube is seen to contain deposit.



Photo 28: The boiler drum of AFBC boiler 1, showing insufficient alkalinity at surface below NWL. The yellow ochre deposits confirm that the FeOH3 was not converting to Fe3O4.



Photo 29: Failed bed coil in another FBC boiler showing deposits.



Photo 30: Color of internal surface of condensate storage tank.



Photo 31: Inspection of steam drum at AFBC boiler 2. Loose powdery iron oxides are seen in the drum. This material is in circulation and it could have deposited elsewhere in the boiler circuit.