FACTORS THAT AFFECT CFBC BOILER FURNACE TUBE EROSION

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Abstract

CFBC technology is a matured combustion technology preferred for wide range of fuels & for locations where fuel quality is inconsistent. CFBC boiler availability has been disturbing at many installations. In this article, we have reviewed the subject of erosion in CFBC boilers for the benefit of the boiler design, erection and operating engineers.

Coal ash chemistry & its fusion temperature

Coal is excavated along with various non-coal material, termed as mineral matter. The mineral matter gets oxidized on combustion. It is customary to analyse the chemical constituents of the ash as listed in table 1. The fusion temperature of the ash should be above 1200 deg C. There are coals with low ash fusion temperature of around 1000 deg C. Such coals require attention to combustion temperature in furnace. There are standard procedures to test the ash fusion temperature of coal ash. One such procedure is outlined in ASTM D 1857 / ISO 540. However, for practical purpose the coal ash can be tested in a lab furnace to know its suitability to fire in the boiler and to understand the limiting combustion temperature. Ash content of a coal is mostly tested at plant lab. This ash can be placed at 1200 deg C to know if it is agglomerating or not. In case the ash melts at lower temperature, the ash would become hard particle and would affect the erosion of the furnace wall panel. Such erosion will be a gross erosion of the wall tubes.

Operating temperature of the CFBC furnace

The operating temperature of the CFBC furnace is dependent on how much evaporating and superheating surfaces are placed in the furnace. In addition, the furnace heat absorption is a function of the fines content in the circulating bed ash / material. Heat transfer in upper furnace is dependent on the amount fines in the upper furnace. The fines content is influenced by many factors. They are:

- Ash content in coal- When the ash content is less than 8%, there can be less fine particle addition from ash. This may not match the depletion from the furnace. This would result in less upper furnace inventory and thus leads to higher combustion temperature. Upper furnace inventory is known by the difference in furnace pressures between kick off zone and cyclone inlet. This is usually in the range of 80 -125 mmWC. Photo 1 shows the case with sufficient solids in the upper furnace. Photo 2 shows the case where the upper furnace DP is 17 mmWC. Less upper furnace DP leads to high FOT and demands high oxygen % to keep the temperature under control. Operation with high EA increases the erosion rate.
- Feed coal particle size distribution- Depending on the top size of coal particles from coal handling plant, fines percentage will be present in the feed coal. High ash coals would have hard ash particles which do not break down in furnace. Less fines in the input coal would lead to high combustion

temperature. Loop seal temperature & furnace exit gas temperatures run high. See photo 3 showing the wide temperature profile & high oxygen % due to use of high size particles as specified by the boiler maker.

- Percentage sorbent (limestone) addition- For sulfur containing fuels, limestone is used for SOx capture. The fineness and composition and the percentage addition would decide the combustion temperature.
- Cyclone collection efficiency / cut off particle size- the design of cyclone is critical for low ash coals. When the fines leave the furnace, the combustion temperature would raise. Fly ash particle sieve analysis proves the efficiency of cyclone. Radial and volute entry configurations have been used by boiler maker. Volute entry with proper velocity would have the best collection efficiency. Boilers with less ash input needs an efficient cyclone. In one case, the cyclone profile was changed by us to improve the collection efficiency. Figures 1 & 2 show two cases with poor cyclone design. We recommend the fly ash is regularly monitored by sieve analysis. See a sample report here.

Fly ash sieve analysis report						
Date & Time	Sieve Size					
	Unit-1			Unit-2		
	>90micron	>75micron	<75micron	>90micron	>75micron	<75micron
6.8.2014	12.5	8.5	79	-	-	-
7.8.2014	12.5	8.5	79	1.5	5	93.5
8.8.2014	7	6	87	2	3.5	94.5
9.8.2014	11	8	81	1.5	4	94.5
10.8.2014	10.5	8.5	81	2.5	5	92.5

- Ash removal rate from furnace / loop seal – inadvertent excess draining of bed material leads to high combustion temperature. A brief period with high furnace temperature can turn the ash to fuse and become harder.

Make up bed material

Make up of bed material will be required for low ash coals and in case, where the cyclone collection efficiency is not designed as per low ash input from coal. In case the bed material contains minerals that fuse at low temperatures, then the bed ash becomes harder. The hardness of the bed ash will increase the rate of erosion.

Make up bed material should have fusion temperature above 1200 deg C. The particle size range for start-up can be 0.5 to 2.35 mm. However, for make-up purpose, the bed material should be < 600 microns. See recommendation in table here.

Recommended make up bed material size	
Microns	*% pass thro*
<600	100
<400	90
<300	50
<250	10

Bed ash reclamation and external recycling system

CFBC boilers fired with low ash coals are sometimes equipped with bed ash reclamation system. Such a system should have a magnet system to separate iron from the ash. This depends on the coal. If the coal contains pyrite, such a system is required. There have been cases where the 3-mm sq. screen size had been selected. The screen opening size can be 1.5-mm sq. only. Photo 4 shows a bed material ash reclamation system with magnetic separator.

Bed ash parameters to check

Whatever be the coal fired or bed material used or sorbent used, ultimately there are some bed ash parameters to be monitored to prevent erosion damage to the furnace wall tubes / wingwall evaporator / wingwall SH panels. They are:

- Bed ash bulk density – Bed ash bulk density is usually in the range of 1400-1450 kg/m3 due to high fines being retained in the furnace. Yet when the ash contains high iron (usually comes in to the boiler as pyrite), the bulk density can reach 1650 kg/m3. The erosion rate of the furnace wall tubes will be higher due to iron accumulation.
- Bed ash iron content- as explained above the iron that comes as pyrite tends to accumulate in the furnace. This increases the erosion rate of the furnace tubes. This will be a gross erosion. It is a must that iron particles are restricted to 10%. The iron particles are to be separated by a magnet.
- Bed ash sieve analysis- There had been a mistake in particle specification by some boiler makers. The coal handling plant should be selected without a prescreen system in the case of low HGI coals. Different coals produce different fines percentage on crushing. For CFBC fines are preferred. In case of higher percentage of coarser particles, say +3 mm, the bed expansion is limited. This leads to high bed temperature. In addition, coarser particles cause high erosion rate. It is general requirement that all particles are less than 6 mm with minus 1 mm in between 30% & 40%. By draining at controlled manner, the coarser particles can be taken out of the furnace inventory. Large size drain pipes tend to remove fines also from the bed. Gates should be throttled so that only coarser particles are taken out.

Loop seal malfunctioning

- Higher capacity boilers are fitted with two cyclones. In case a loop seal is plugged, the bed temperature would rise. This causes the bed material to become harder. The boiler may continue to generate rated steam with rise in furnace temperature. There are cases of fallen vortex finder and the boiler continued to operate.
- In the case of single cyclone, the transfer rate could be disturbed due to partial plugging. On full plugging of the loop seal, there will be uncontrollable bed temperature rise. This can be known only by proper and adequate instrumentation at the loop seal. Due to partial plugging, the bed temperature can rise. Plugging can occur due to any of the following reasons.
    - Nature of sorbent
    - Inadequate air flow at loop seal
    - Plugging of air nozzle
    - Failure of air nozzle and filling of loop seal windbox
    - Refractory spalled from above or at the loop seal itself and affecting material transfer

Inlet configuration to cyclone- preferential erosion of side walls.

- The gas inlet configuration to cyclones can cause erosion of the side walls. See figure 3. The gas flows along the side walls before entering in to the cyclones. The side wall panel gets eroded due to this effect. See photo 6 showing the side wall erosion.

- The cyclone inlet wall angle can be altered as in figure 4. Some manufacturers are yet to adopt this feature.
- In figure 5, the cyclone entry is at the center. This may cause the material to drop out along the side walls, depending on the % width open at rearwall. Not all the bed inventory enters cyclones. Some fall out of stream. This cause internal recirculation of solids. This is the reason some part of the side walls and rear wall panels are refractory lined.

Arrangement of wingwall panels

The arrangement of the wingwall panels should be equally spaced. Too close a spacing can cause preferential internal recirculation of solids. Figure 3 shows the boiler, wherein uneven arrangement of wingwall panels have resulted in preferential gas flow and resulted in thinning down of the roof tubes. Photo 8 shows the roof tube failure in the above case. Figure 6 shows the thickness mapping when the erosion failure occurred at this boiler. Around 20 tubes from each side wall only shows up erosion. The thinning has taken place within 2 years of boiler operation.

Narrow inlet configuration to cyclone- preferential erosion of side walls.

The gas inlet configuration shown in figure 7 is bit odd. There will be fall out of material in between the two gas flow paths at cyclone entry. This is because gas flow opening width is much less as compared to the width of the rear wall. The rear wall is subject to high recirculation of solids. The heat pick-up pattern also can be different due to this. As the gas flow is along the side wall panel, the entire side panels would need protective refractory lining.

Improper refractory lining

Refractory lining defects fall in to following subcategories.

- Refractory design at lower furnace
    - The anchor design adopted with thick refractory lining had been subject to thermal spalling due to heating and cooling cycles. A tube leak is sufficient to create damage to the refractory. See photo 9.
    - There are cases of improper refractory design at lower part of furnace. Of all the designs adopted the use of LC castable with use of studs welded to tubes prove to be the best. See photo 10. However, around the fuel feed opening and other openings high alumina plastic refractory is desirable.
    - One manufacturer provides a multilayer design, which is the worst design of all from maintenance point of view. See figure 8 & photo 11.
- Refractory spalling due to thick sections
    - Thick refractory sections in excess of 50 mm may be used for the various openings such as fuel feed points, SA ports, ash recycle openings and start up burners would spall and create

  - havoc. The tubes get exposed locally and are subject to localized erosion. This is frequently seen during shut down inspection. See photo 12.
  - The spalled refractory blocks lead to erosion failure of air nozzles. This is quite a dangerous situation leading to hot bed material pouring in to windbox. See photo 13 & 14.
- Improper refractory geometry at corners
  - CFBC combustors are invariably of rectangular cross section. The upward gas flow is at the center and the particle downflow is high along the wall. The erosion rate has to be monitored in CFBC boilers on every annual shut down. This is not the case with other combustion technologies. Generally, fins cannot be closed accurately at the corners. This also add to local fin-tube profile defects. See photos 15 & 16 showing corner tube erosion. Some manufacturers provide corner refractory. Some boiler makers do not provide this.
  - The cyclone entry geometry causes preferential erosion along the front wall corners. Low load operation enhances this effect. This also demands furnace corner refractory.
  - Where the furnace corner refractory is provided, improper geometry is adopted by some boiler makers. The good and bad corner refractory details are illustrated in figure 9.
  - Refractory ends cannot be finished with thin edges. Thin edges simply break away and create zig zag paths for material flow. Localized craters are created on the tubes in this area. See photos 17 & 18.
- Improper refractory geometry at kick off bend zone
  - Kick off zone is a design detail added in CFBC combustor during the development & scale up process. Some designs do not have this. Instead alternate arrangements are provided. As the particles travel down at good speed, the refractory applies a brake. The dissipation of kinetic energy causes in erosion of both refractory & tubes nearby. When the refractory is in excess, the refractory erodes. Due to installation mistakes in refractory contour, the tubes can erode. See photos 19 & 20 showing the erosion of refractory and tube. Figures 10 -12 show the refractory profile requirement at kick off zone. It is recommended to have 90% alumina plastic refractory at the kick off zone (around 500 mm height) to slow down the erosion rate of refractory.
- Improper anchor design / Excess refractory at wingwall evaporator / superheater at bottom
  - Except for the vertical part of the wingwall panels, the rest of the panel is covered with LC refractory or plastic refractory. This should be a thin refractory with adequate studs. Any other details would fail. See photo 21 & 22 showing improper protection. Figure 13 shows the improper engineering of wingwall SH / Evaporator bottom tube protection system. When the studs are inadequate or when the refractory thickness is excess, spalling is encountered. Then the bottom most tube of the wingwall evaporator / SH fails by erosion. If the refractory thickness is more than 40 mm there is vulnerability of spalling. See photo 23 showing the spalling of refractory due to excess refractory. Figure 14 shows the correct refractory detail to be followed.

Improper panel manufacture – erosion due to manufacturing defects

- Not every manufacturer is clear on this. Unlike the PF boiler / AFBC boiler / stoker fired boilers / gas or oil-fired boilers, CFBC furnace panels demand stringent quality levels during manufacture

& during field work. Manually welded panels is not acceptable. Only panels made by automatic welding machines are to be used. Panels coming under refractory lining can be made by manual welding process. Figure 15 states the important quality requirements during the production & construction stage.
- Several defects such as out of alignment tubes & fins, excess welding at fins, non-removal of tube & fin butt weld beads, bowing of panels cause preferential erosion. These are explained in this article.

Improper erection of furnace wall panels

Not all erection engineers or erection contractors are clear on quality requirements of the furnace panel assembly. Furnace wall panels are sent in parts due to transport and erection constraints. Field work demands stringent quality levels. Some of the serious defects and the effects are listed here.

- Failure to remove the tube & fin buttweld beads lead to localized erosion patterns which ultimately lead to tube failure at the fin-tube weldments. This is illustrated in figure 16-18. Photo 24 -27 show real life examples.
- Fin filler plates are to be properly placed in plane. The welds should be of full penetration welds and the excess beads are to be ground off. Portable pencil grinders / carbide cutting tools are to be used to remove the weld beads on the fire side. Photos 24 & 27 show the detrimental effect of the defects.
- Panel fins which are slit for alignment purpose are to be sealed with full penetration welds. The beads are to be ground flush afterwards. Generally during construction, the panel to panel weldments are carried out from outside the furnace. CFBC boiler demands scaffolding inside in order to carryout full penetration welds and to flush grind all the tube to tube butt weldments, fin to fin butt weldments, fin closures at field joints.
- The furnace wall panels have to be absolutely vertical in both Y-Z planes. Failure to maintain verticality leads to gross erosion of panels. Photo 28 shows the erosion of tubes near the field weld, where vertical alignment is compromised. Figure 15 shows the mechanism. See photo 29 showing the localized panel erosion due to the presence of bow in the panel. On one wall, just one panel may alone get eroded in a peculiar manner when verticality is compromised. See photo 30 & 31 showing the patch erosion due to the out of verticality defect. Figure 20 illustrates the mechanism.
- No scrap can be left on the fire side anywhere. Or else local failure will be encountered. Even a thermocouple inserted in the furnace will be subject to erosion. Not only the thermocouple would be cut, but also the panel tubes nearby will be eroded off. Photo 32 shows the panel tube erosion near the thermocouple insertion point. Figure 21 illustrates the mechanism. Retractable thermocouples are recommended below the wingwall SH for start- up flue gas temperature control purpose.
- Pressure tapping are permitted in the CFBC combustor. Again, the tapping should be in flush with the fin.
- Periodical replacement of panels may be required in CFBC boilers. The replacements may be warranted within a period of 5 years depending on the coal ash particle abrasiveness and other construction defects. Usually the replacement will be a length of 5 m from the bottom tapered

panels. Such replacement panels are also to be fabricated using mechanized panel manufacturing machine with auto SAW or auto MIG technology. A compromise results in frequent outages. See photos 33-35 driving the point.

Improper metal spray

- Metal spray technology had been developed for reconditioning worn out components in several industries. This has been extended to CFBC boilers. Some boiler makers apply this technology for furnace wall panels that come above the kick off zone. This is the place where the panels have a shorter life. This is because the velocity & particle density is maximum here. See figure 22, showing the flow of solids in CFBC furnace. Photo 36 shows the erosion effect on the kick off zone refractory.
- HVOF spray with wear resistant materials to a thickness of 100-150 microns have been tried by many. Field application had been a disaster. This is because HVOF spray cannot applied properly by manual process at field conditions. Improper angle & distance and non-uniform layer thickness have led to miserable failure. Even panels with first supply with HVOF spray had failed in 3 years' time. See photo 37 -39 showing actual experience from two different plants.
- Users who have tried under field conditions revert back to regular furnace panels. This gives longer life as compared to metal sprayed panel.

Part load operation

Part load operation result in internal recirculation of solids within the furnace. The flow through the cyclone & loop seal would reduce. In case of two cyclone system, there can be high temperature at one loop seal due to short circuiting of gas from furnace to loop seal. This is noted by the difference in loop seal temperature. The material flow pattern is not predictable. Prolonged operation can cause issues. There are cases that one or two walls appear to be polished.

Deviation from design fuels

The design of furnace, cyclone & loop seal etc are designed for a specified fuel. The gas quantity can largely differ when high moisture / low GCV fuels are fired. There are cases where the design moisture is 10% and as fired moisture is 30% - 38%. The flue gas velocity could be higher causing high erosion rate at target zone of the cyclone. Design fuels should be specified on air dried basis instead of as received basis. This is particularly applicable to Indonesian coals.

Malfunctioning of vortex finder

The vortex finder can be subject to distortion due to tube leaks. See photo 40 & 41. Vortex finder may be subject to distortion due to constraints in thermal expansion. This leads to differential gas flow between the cyclones. This leads to unbalanced gas flow within the furnace. It can result in short circuiting of flue gas through the loop seal. This can also show up difference in erosion pattern of the furnace wall panels. It is seen that the cyclones show up difference in erosion pattern.

Variation in gas flow between cyclones- cyclone construction

The cyclone can be made from steam cooled tubes or water-cooled tubes or it can be of refractory construction. The most important part of cyclone is the bull nose in the cyclones, in the case of refractory construction. Difference in opening dimensions / shape can cause differential gas flow. There will be difference in collection rates of ash between cyclones. This will cause internal recirculation of solids within the furnace. There will be uneven erosion of refractory. Photo 42 & 43 shows the erosion of vortex finder. The refractory erosion showed a large difference between two cyclones.

Variation in gas flow between cyclones- inadequate upper furnace density / DP

When the upper furnace inventory is less the loop seals show difference in temperature. The collection rate would be different. This is due to inadequate resistance for the gas flow. Short circuiting of flue gas takes place as the flow of solids in downleg will be less.

Imbalance in fuel feeding

Number of fuel feed points are provided in the design to distribute the fuel equally, in the way air is well distributed by grid nozzles and SA ports. Some boiler engineers ignore this and choose to feed coal with large unbalance. This can cause preferential internal circulation of the solids.

Erosion of furnace tubes around SA ports

SA nozzles setting should be projected inside the furnace to a minimum length. In cases where the nozzles are left inside the refractory seal box, the refractory erodes / spalls over a period. Subsequently the tubes around the SA port opening begin to erode. See photo 44 & 45 and figure 23.

Erosion protection for furnace wall panel above Wingwall SH / Evaporator openings

As discussed earlier, any protrusion in the furnace walls would be subject to erosion. For this reason, the wingwall SH and wingwall evaporator are covered with high alumina refractory at the penetrations. Now the refractory itself becomes a disturbing element causing the panel tube erosion. See figure 24 and photo 46 & 47 emphasizing the point. The erosion protection is chosen between weld overlay and HVOF spray.

- Weld overlay is seen to last longer. Only care is to be taken to have a smooth transition between bare tube and the overlaid portion.
- Metal spray or weld overlay is found required for 200 mm length. The overlay has to be completed before applying the refractory since a 50-mm overlapping is a must between refractory and the overlay.
- HVOF metal spray can be adopted only if proper working conditions are made available.

- The sloped refractory face is important to reduce the erosion rate.
- The contouring of refractory along the tube is important as required for furnace corner refractory.

Erosion protection of wingwall SH / Evaporator above the refractory

The wingwall SH or evaporators are protected from erosion at the bottom zone. This is specifically required as the wingwall SH / Evaporator tubes are oriented horizontally to the solids flow direction. Once the tubes are oriented vertically the erosion rate is greatly reduced. However, the transition zone between the refractory and the vertical tubes is susceptible to erosion. In this zone, metal spray or HVOF spray is applied. See photo 48 & 49. HVOF metal spray has its limitation with respect to dry heating during start up. Field repair is not successful unless it is executed with complete removal of previous coating. Weld overlay is found to be simpler. The transition zone is between weld overlay and the bare tube should be ground smooth. The refractory should be sloped at 45 deg to allow free flow of solids.

Limestone chemistry

There are boilers which use petcoke. Petcoke contains high sulfur. In order to limit the SO_x emission, limestone is fed along with petcoke. The quality of the limestone could vary from location to location to large extent. Petcoke does not contain ash. Hence the bed inventory is made of limestone in this case. The silica and alumina content decide the baking effect at loop seal downleg and the flowability in the loop seal outlet duct. The inerts available in limestone improve the flowability of solids. There are cases where the flowability of ash had been poor. This results in partial plugging / full plugging of loop seal. If this is not noticed, there can be high internal solids circulation within the furnace. This can increase the erosion rate depending on the inert content of limestone.

Conclusion

The CFBC technology is opted to reduce the unburnt carbon levels in fly ash so that the ash becomes usable at cement industry. The gain in efficiency is a matter of how much is the ash content and what is the GCV of fuel. CFBC boiler needs high head PA, SA and ID fans and hence the auxiliary power consumption is high. Yet a user knowingly opts for CFBC for the benefit of carbon loss. We have compiled our observations from design / operational / shut down auditing of several CFBC installations and presented here. Boiler manufacturers are required to give a good installation without the defects highlighted in this article. If the reader has a feedback, please write to venus1@venus-boiler.com or to parthi2006@gmail.com.

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TABLE 1: COMPARISON OF ASH CHARACTERISTICS of SOME COALS							
		US coal	South Africa	Russian	Poland	Indonesian coals	
As received fuel moisture	% wt	8	8	8	8	13.9	20.5
Sulfur in coal	% wt	0.71	0.52	0.33	0.50	1.1	0.3
ash percent in fuel	% wt	17.51	14.33	11.12	14.77	8.2	4.8
GCV as fired	Kcal/kg	6214.1	5923.3	6437.34	6409.0	5532.00	4514.00
Ash Chemical composition							
Silica	SiO2	49.46	54.90	57.39	49.75	52.10	38.50
Alumina	Al2O3	26.76	29.80	20.35	25.31	26.82	16.43
Titanium oxide	TiO2	1.49	1.35	0.86	1.24	1.16	1.00
Ferric oxide	Fe2O3	3.71	5.05	5.67	8.59	10.52	9.42
Calcium oxide	CaO	7.27	2.20	5.72	4.22	1.80	9.44
Magnesium oxide	MgO	1.85	1.05	2.16	1.85	1.38	4.03
Sodium oxide	Na2O	0.50	0.24	1.26	1.15	0.65	4.73
Pottassium oxide	K2O	0.78	3.55	1.93	2.44	2.80	1.07
Sulfur trioxide	SO3	5.74	0.72	3.35	4.78	1.47	14.31
Phosphorous oxide	P2O5	1.38	0.12	1.00	0.54	0.50	0.37
Manganese oxide	MnO2	0.07	0.05	0.06	0.13	0.00	
trace metals	XX	0.97	0.97	0.25	0.00	0.80	0.70
Ash fusion temperature (reducing atmosphere)							
Initial deformation temp	Deg C	1345	>1500	1249	1210	1310	1120
Hemi spherical temp	Deg C	1375	>1500	1288	1330	1359	1140
Flow temperature	Deg C	1415	>1500	1340	1430	1470	1190
Ash nature- empirical parameters compared							
Base to acid ratio		0.18	0.14	0.21	0.24	0.21	0.51
Silica ratio		0.79	0.87	0.81	0.77	0.79	0.63
Slagging index		0.13	0.07	0.07	0.12	0.24	0.15
Fouling index		0.18	0.36	0.54	0.66	0.53	2.79
Iron loading	kg/Mbtu	5.81	6.79	5.44	11.00	8.69	5.59
Sodium content	%	0.5	0.24	1.26	1.15	0.65	4.73
Total alkali content	%	1.014	2.579	2.532	2.758	2.495	5.435
Ash fusion temp-V1<0.2 high	0.2	High	High	Low	Low	Low	Low
Deposit removal-V2>0.8 Easy	0.8	Tough	Easy	Easy	Tough	Tough	Tough
Slagging nature-V3<0.6 Low	0.6	Low	Low	Low	Low	Low	Low
Fouling nature V4<0.2 No	0.2	No	Yes	Yes	Yes	Yes	Yes
Iron loading, V5>0.3 high	0.3	high	high	high	high	high	high
Alkali per 10^6 kcal		0.286	0.624	0.437	0.636	0.371	0.580
Fe2O3 Per 10^6 Kcal		1.045	1.222	0.980	1.980	1.565	1.006
Quartz: Sio2/Al2O3		1.85	1.84	2.82	1.97	1.94	2.34
Qc,Quartz content 0.01*ash*(SiO2-1.5Al2O3)		1.63	1.46	2.99	1.74	0.98	0.67
Pc,Pyrite content 1.2*(S-0.3)		0.49	0.27	0.03	0.24	0.96	0.00
Abrasion Index Qc + 0.5*Pc + 0.2*Ac		5.38	4.46	5.23	4.81	3.10	1.63

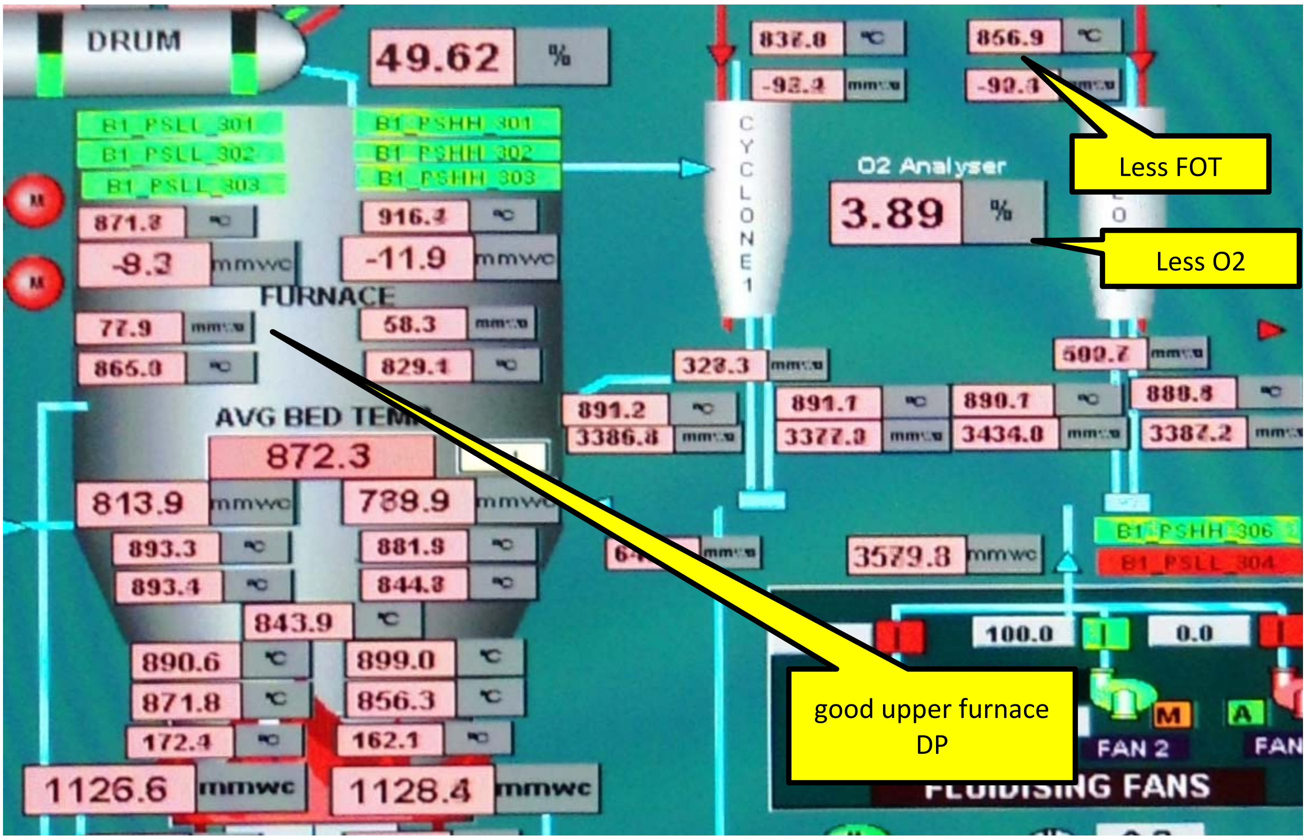


Photo 1: The above shows the upper bed DP of 78 mmWC. The average bed temperature is 872 deg C. The oxygen in flue gas is under control.

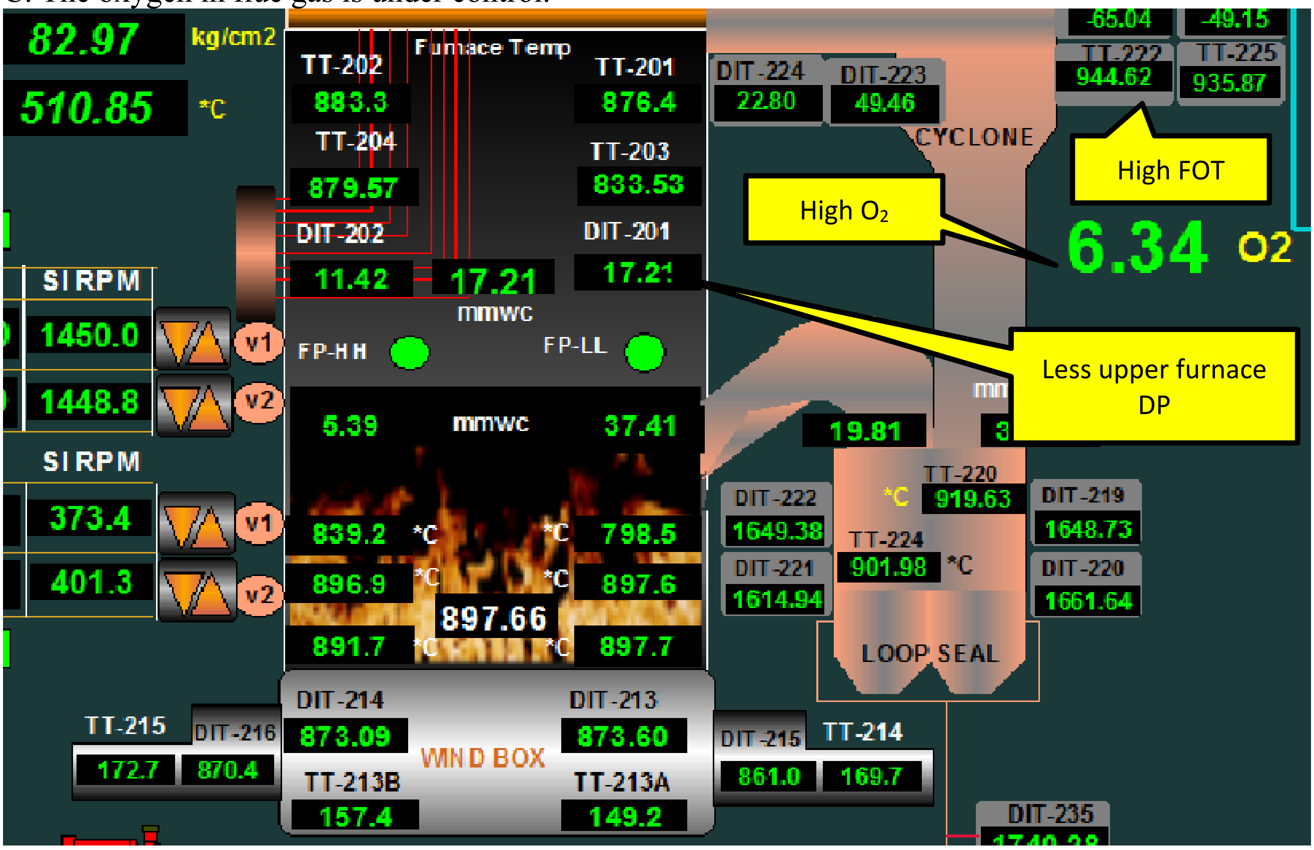


Photo 2: The upper furnace DP is hardly 17 mmWC. The cyclone outlet temperature is 936 & 945 deg C even with O_2 at 6.34%. The cyclone had not been performing well or the solids input from fuel had been less. It is net retention effect of addition, depletion of fine solids to furnace.

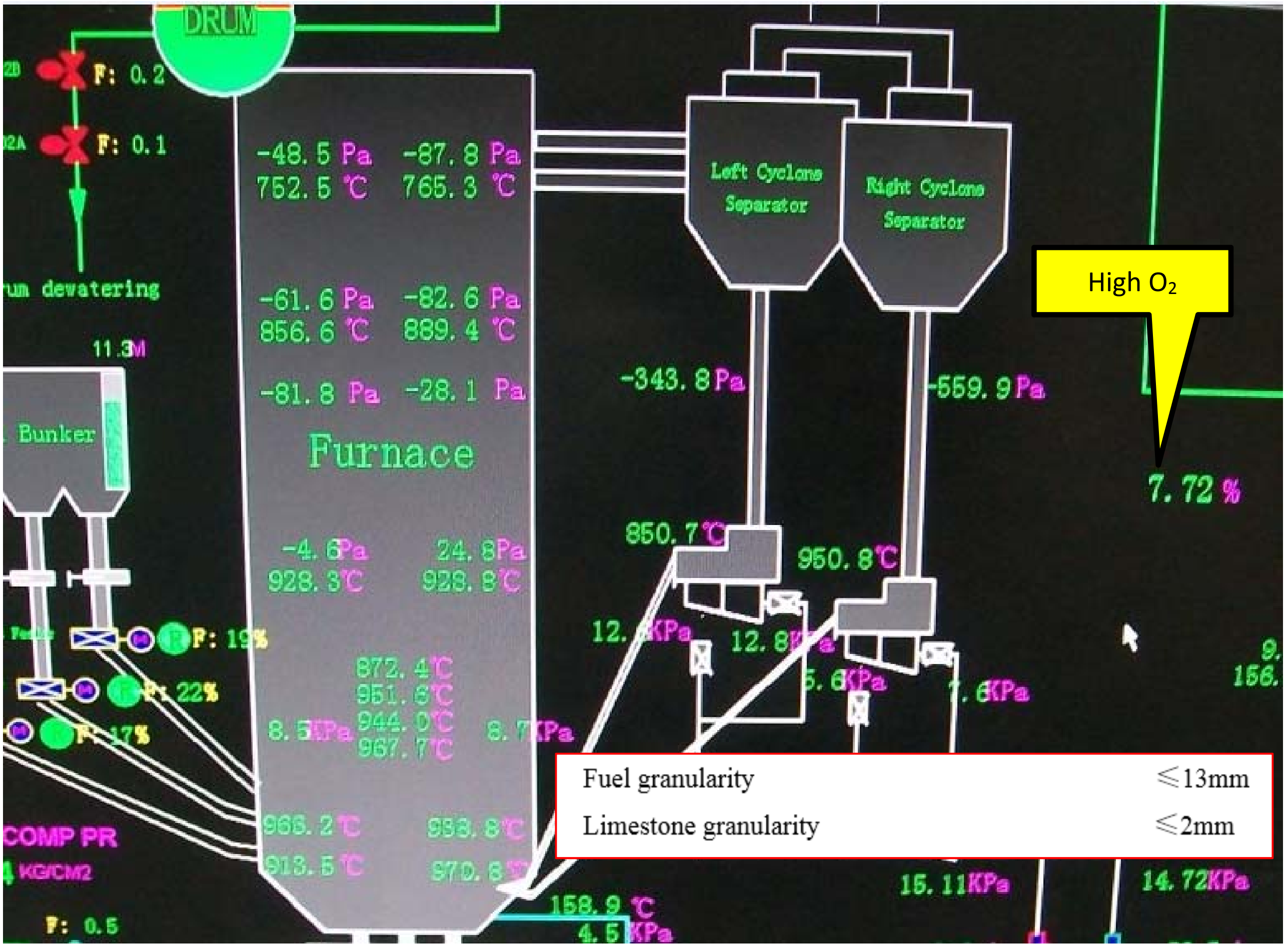


Photo 3: The above is a case of wrong specification of fuel. The supplier had specified coal particle size as 13 mm. The upper furnace DP has been only 60 Pa. This is too less. The oxygen level is 7.72%. The loop seal temperatures differ by 100 deg C. Furnace bottom to top temperatures show 200 deg C difference. Altogether the boiler was not working as CFBC.

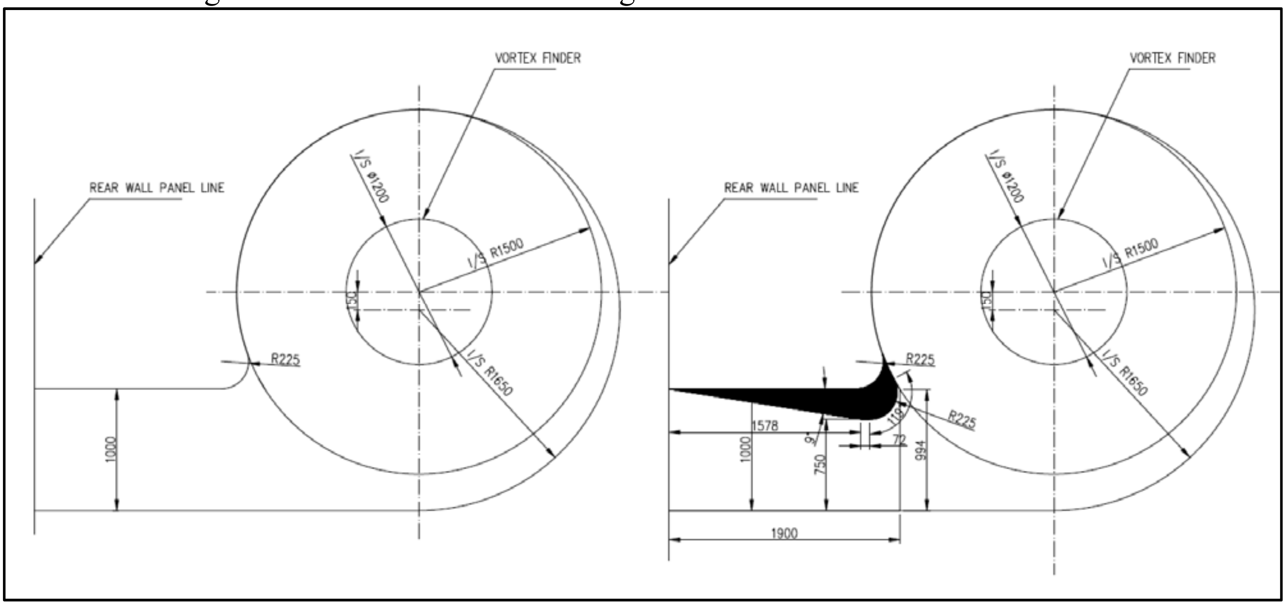


Figure 1: The above photo shows the modification of the radial entry cyclone with volute entry. The +90 micron particles in ESP fly ash came down from 25% to 9% after this modification. Otherwise the loss of fines from the furnace was high and furnace exit temperature had been +950 deg C. The exit temperature came down to 875 deg C after the modification.

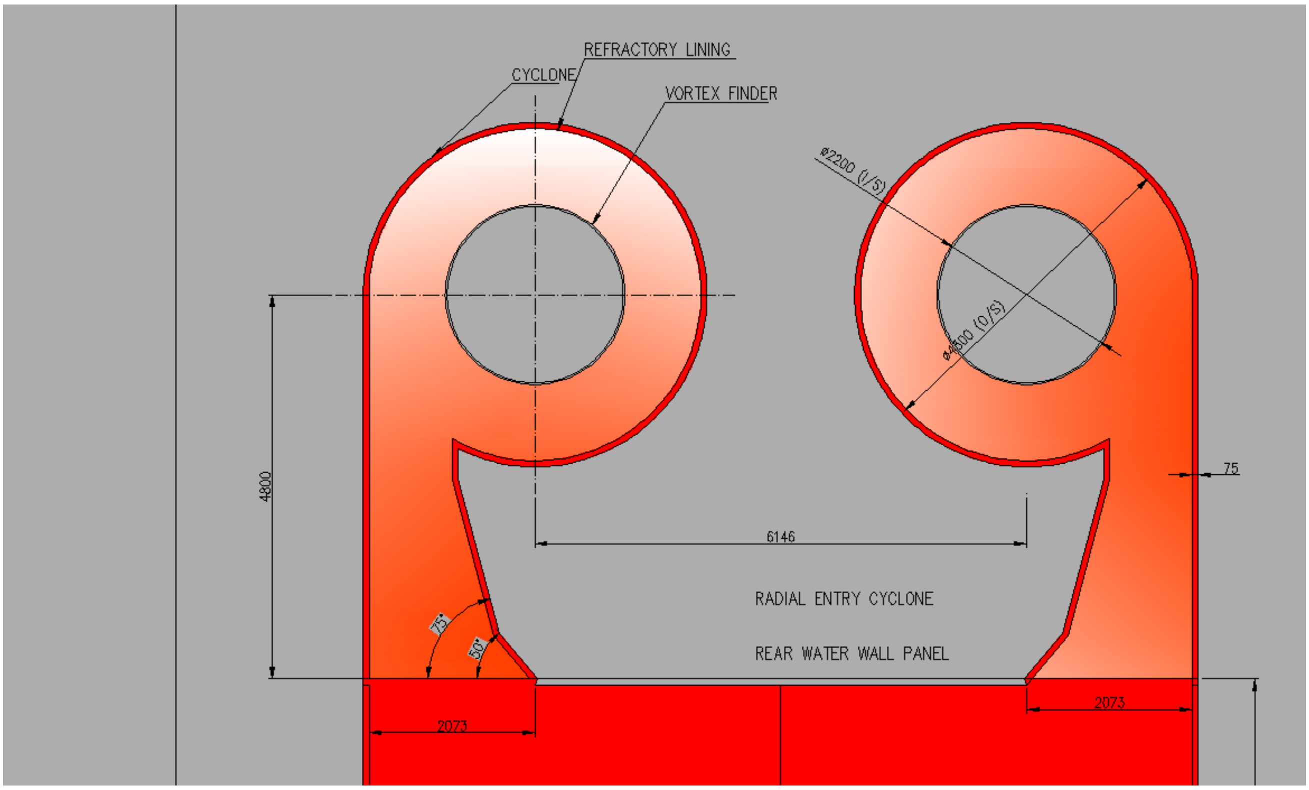


Figure 2: The cyclone configuration shown is a radial entry cyclone which resulted in a poor collection efficiency. This demanded the cofiring of high ash Chilean coal along with the design Indonesian coal. Otherwise the bed inventory retention was very poor.

Photo 4: Drum type magnetic separator is used at plant to separate iron from bed ash. This will help to avoid rise in iron in solids inventory in the furnace. This is applicable for pyrite containing coals.

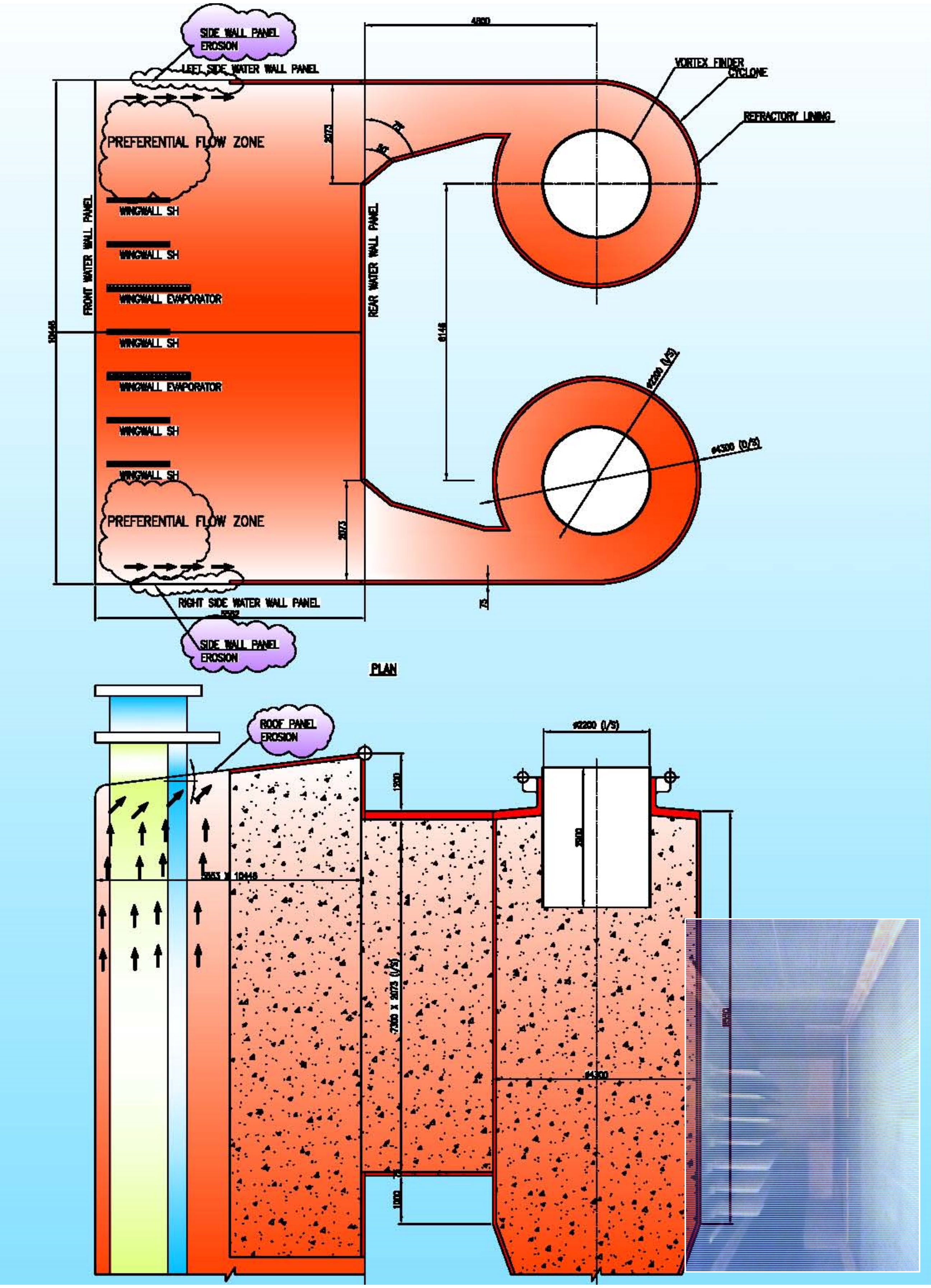


Figure 3 & Photo 5: The above shows a boiler with two cyclone system. The erosion is seen in side wall panels, because the entry to cyclone is along the two side walls.

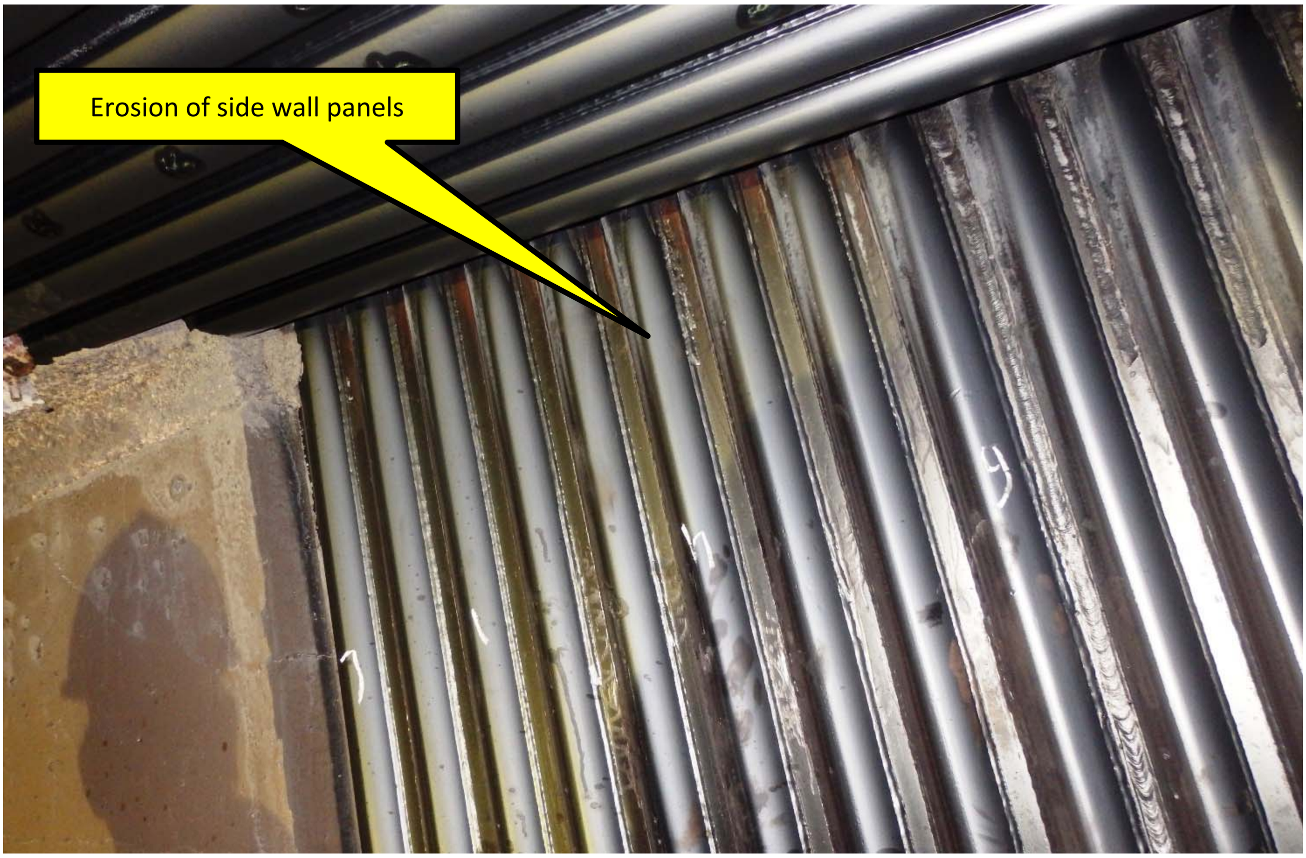


Photo 6: The above photo shows the erosion of side wall panels in the boiler with cyclone entry configuration as in figure 3.

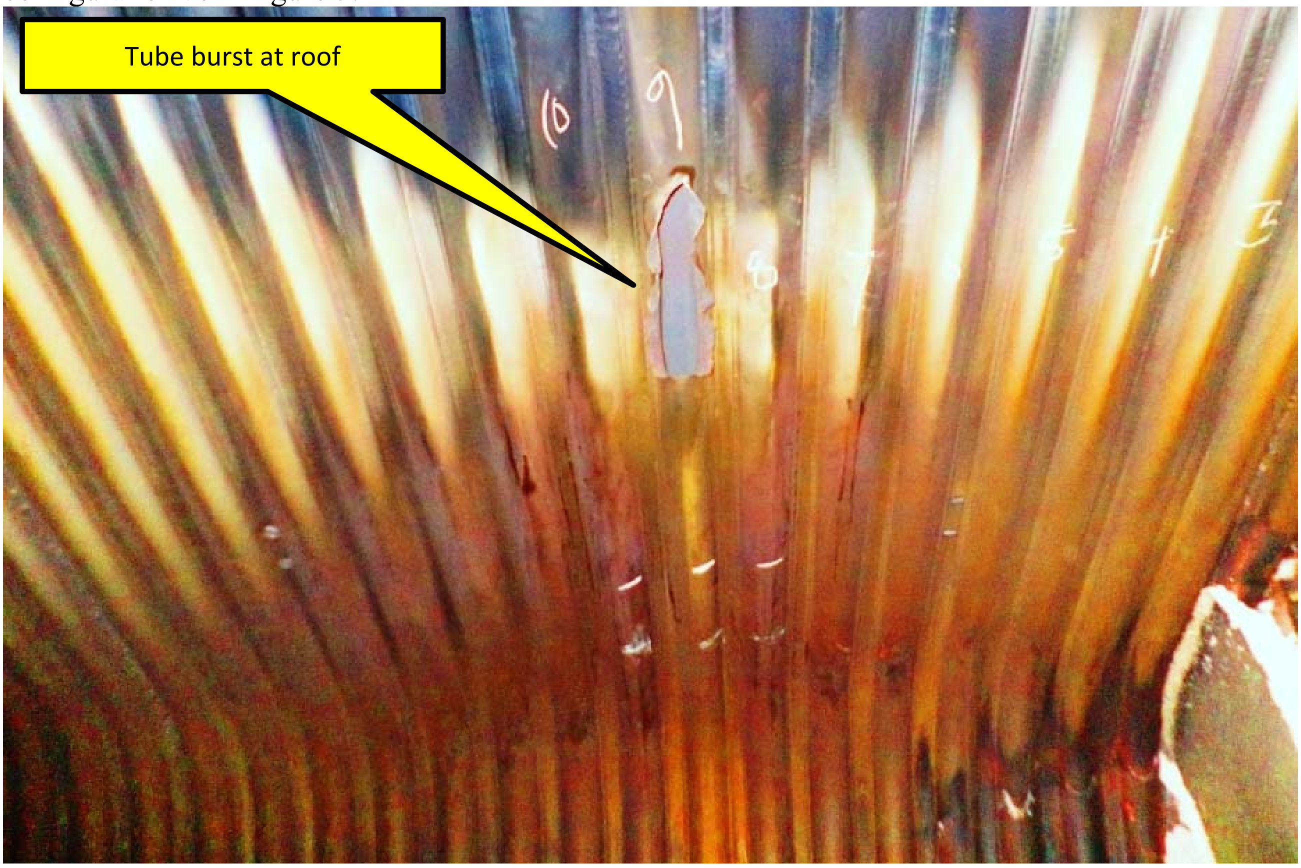
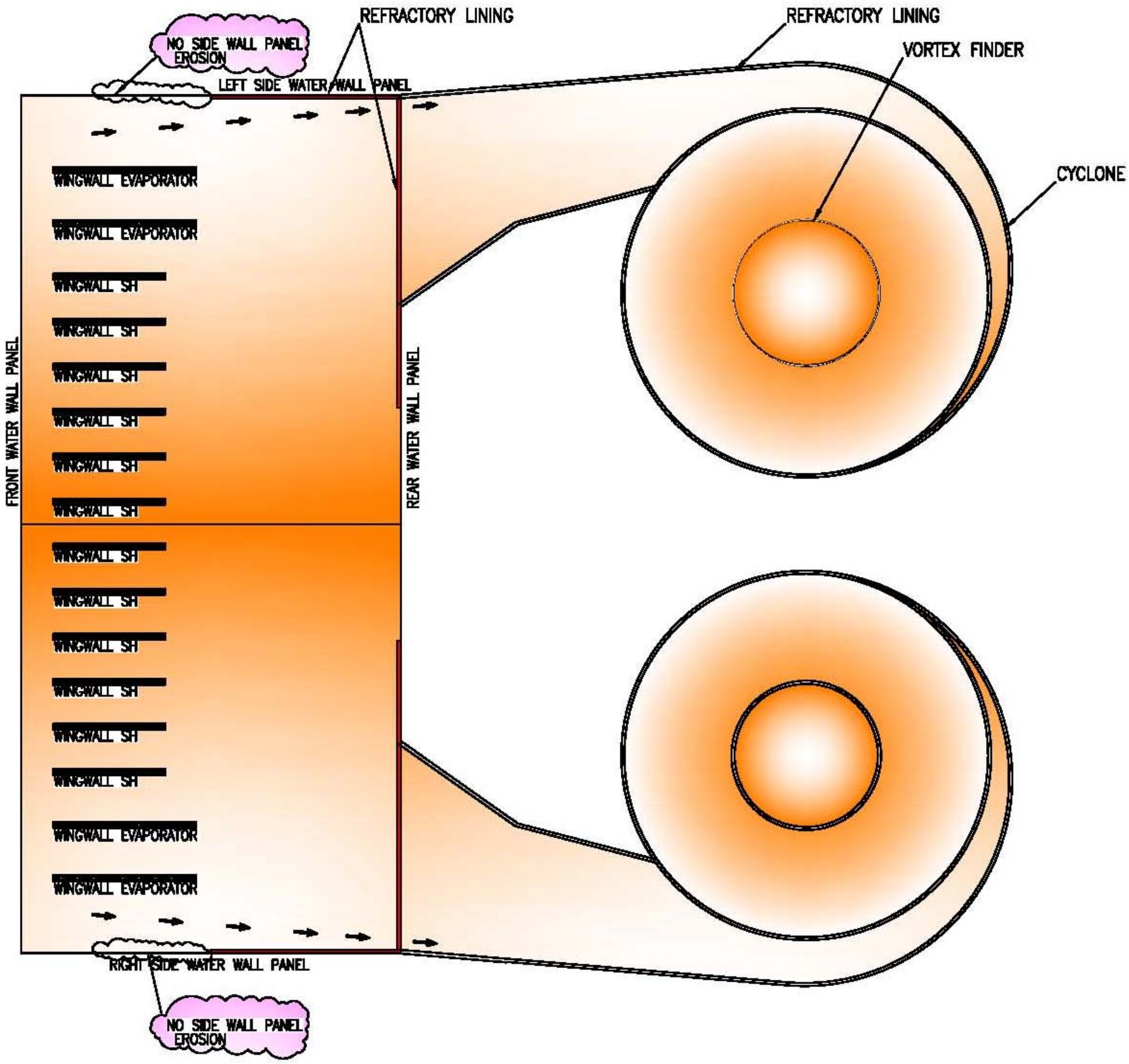


Photo 8: The above photo shows the eroded roof panel and the burst roof tube. The arrangement of wingwall SH / Evaporator had allowed preferential gas flow as shown in figure 3.



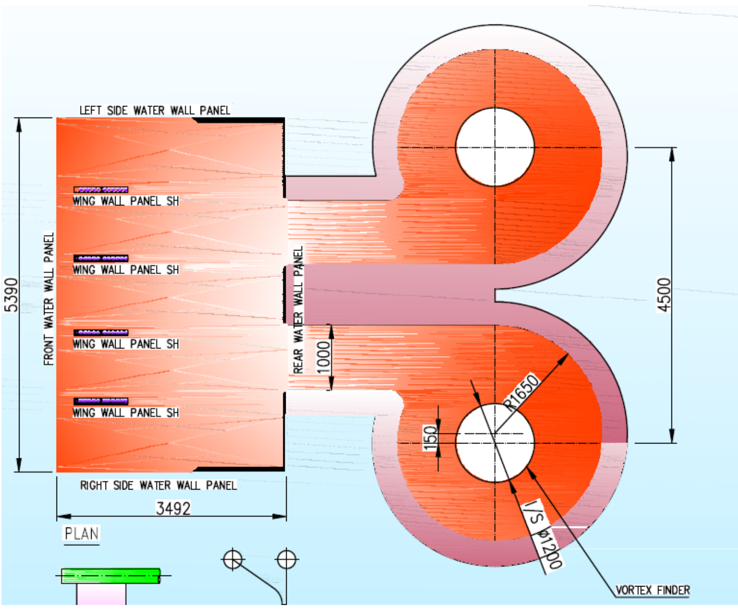


Figure 4: The above shows a boiler with two cyclone system. The erosion along the side wall is prevented by the design of the cyclone inlet wall plane. The gas entry to cyclone is volute. This cyclone was found to perform well. The +75 microns particles were the least in this unit.

Figure 5: The left side figure shows central entry to cyclone. This prevents the erosion of side wall tubes. But this can increase the dust flow towards side corners. If the entry is wider, this problem would not be experienced.

TUBE NO	Lj	Li	Lh	Lg	Lf	Le	Ld	Lc	Lb	La	L	L1
1					5.0	4.9	5.0	4.9	4.8	5.2	5.2	4.9
2				4.0	4.5	4.4	4.0	*	*	3.5	3.9	4.9
3	3.9	3.8	3.7	3.5	3.7	3.4	2.2	*	*	2.6	3.3	4.4
4	4.0	4.5	3.7	3.7	3.2	2.9	1.6	*	*	2.1	2.9	3.9
5	4.0	3.9	3.7	3.5	3.4	2.9	2.4	*	*	1.5	2.1	3.1
6	3.9	3.8	3.7	3.5	3.3	2.9	2.7	*	*	1.8	1.5	3.3
7	3.9	3.7	3.4	3.2	3.2	2.1	2.1	*	*	2.0	1.4	3.2
8	3.9	3.9	3.4	3.5	3.1	3.0	2.4	*	*	2.8	1.2	2.7
9	4.7	4.5	3.6	4.0	3.3	2.8	2.7	*	*	2.1	1.4	2.2
10	4.3	4.2	4.3	3.9	3.9	3.3	3.7	*	*	1.5	1.8	1.5
11		4.3	4.0	4.3	3.3	3.5	3.2	*	*	2.9	1.6	2.8
12			4.4	4.0	4.1	3.2	3.7	*	*	2.4	2.2	3.4
13					4.1	4.0	3.6	*	*	2.4	2.0	1.4
14					4.4	3.9	3.7	*	*	2.6	2.2	1.2
15					4.2	3.7	3.2	*	*	2.7	2.7	3.3
16					4.2	4.2	3.9	3.8	3.2	2.8	2.8	3.3
17					4.4	4.0	4.0	4.0	3.4	3.1	3.1	3.5
18						4.0	4.2	3.7	3.7	3.1	3.2	3.7
19						4.0	4.0	3.9	3.6	3.5	3.2	3.6
20						4.4	4.2	4.0	3.8	3.5	3.5	3.7
21							4.3	4.5	3.8	4.0	3.9	4.3
22							4.6	4.3	4.3	3.9	3.9	3.9
23							4.5	4.1	4.1	3.8	3.6	3.2
24							4.2	4.3	3.9	4.0	3.9	4.2
112			4.9	4.9	4.9	4.9	4.9	4.4	4.6	4.4	4.2	4.5
113			4.9	4.9	4.9	4.8	4.7	4.4	4.2	3.3	3.4	4.1
114			4.6	4.6	4.5	4.5	4.2	4.1	3.8	3.6	3.3	3.8
115			4.9	4.6	4.5	4.7	4.5	4.1	3.4	3.7	3.3	3.8
116			4.9	4.8	4.6	4.5	4.2	4.0	3.8	3.3	2.9	3.5
117			4.7	4.7	4.4	4.6	4.1	3.6	3.2	2.9	2.4	3.1
118			4.8	4.5	4.3	4.5	3.9	3.8	3.6	3.2	2.8	3.1
119			4.8	4.8	4.3	4.5	3.8	3.7	3.4	2.8	2.5	2.7
120			4.6	4.8	4.3	4.3	3.8	3.5	3.4	2.9	2.6	2.4
121			4.6	4.5	4.3	4.6	4.1	2.4	2.2	2.7	2.3	2.4
122			4.9	4.5	4.2	4.2	3.6	3.1	2.9	2.3	1.9	2.9
123			4.4	4.4	3.9	4.1	3.5	2.9	2.6	2.1	1.8	2.2
124			4.3	4.1	3.7	3.9	3.3	2.8	2.4	1.9	1.5	2.0
125			4.3	4.1	3.6	3.8	3.0	2.6	2.1	*	2.3	1.9
126			4.2	4.2	3.4	3.7	3.0	2.7	2.4	*	*	1.9
127			4.4	3.7	3.6	3.8	2.8	2.3	2.0	*	*	*
128	4.3	4.2	4.1	3.6	3.4	3.5	2.7	2.2	2.0	*	*	1.7
129	4.2	4.1	3.9	3.6	2.9	3.2	2.5	2.0	*	*	*	1.5
130	4.1	4.0	3.9	3.6	3.0	3.2	2.5	2.2	*	2.0	1.8	1.9
131	4.1	4.0	3.9	3.6	2.9	3.2	2.6	2.0	1.5	2.4	*	1.9
132	4.2	3.9	3.9	3.6	2.8	3.1	2.4	2.1	1.6	2.0	1.5	1.5
133	4.3	4.0	3.9	3.6	3.3	3.5	2.8	2.3	1.9	1.7	1.5	2.2
134	4.1	4.0	3.9	3.9	3.0	3.2	2.8	2.4	2.2	1.9	1.6	3.5
135	4.4	4.1	4.1	3.7	3.4	3.6	3.2	3.0	2.6	2.4	2.5	3.9
136			4.5	4.4	4.1	3.9	3.9	3.7	3.4	3.5	3.4	4.6
137			4.9	4.8	4.8	4.9	4.5	4.6	4.9	4.5	4.9	4.8

(shaded) <3.4 MM thk tubes

Figure 6: The top table shows the erosion pattern of the roof tubes (in front of the normal roof lining) in the wingwall SH / EVAP configuration shown in figure 1 & photo 8. Only 24 roof tubes on either side of the combustor & towards the cyclone entry had thinned down. Based on the pattern of erosion refractory protection zone was increased.

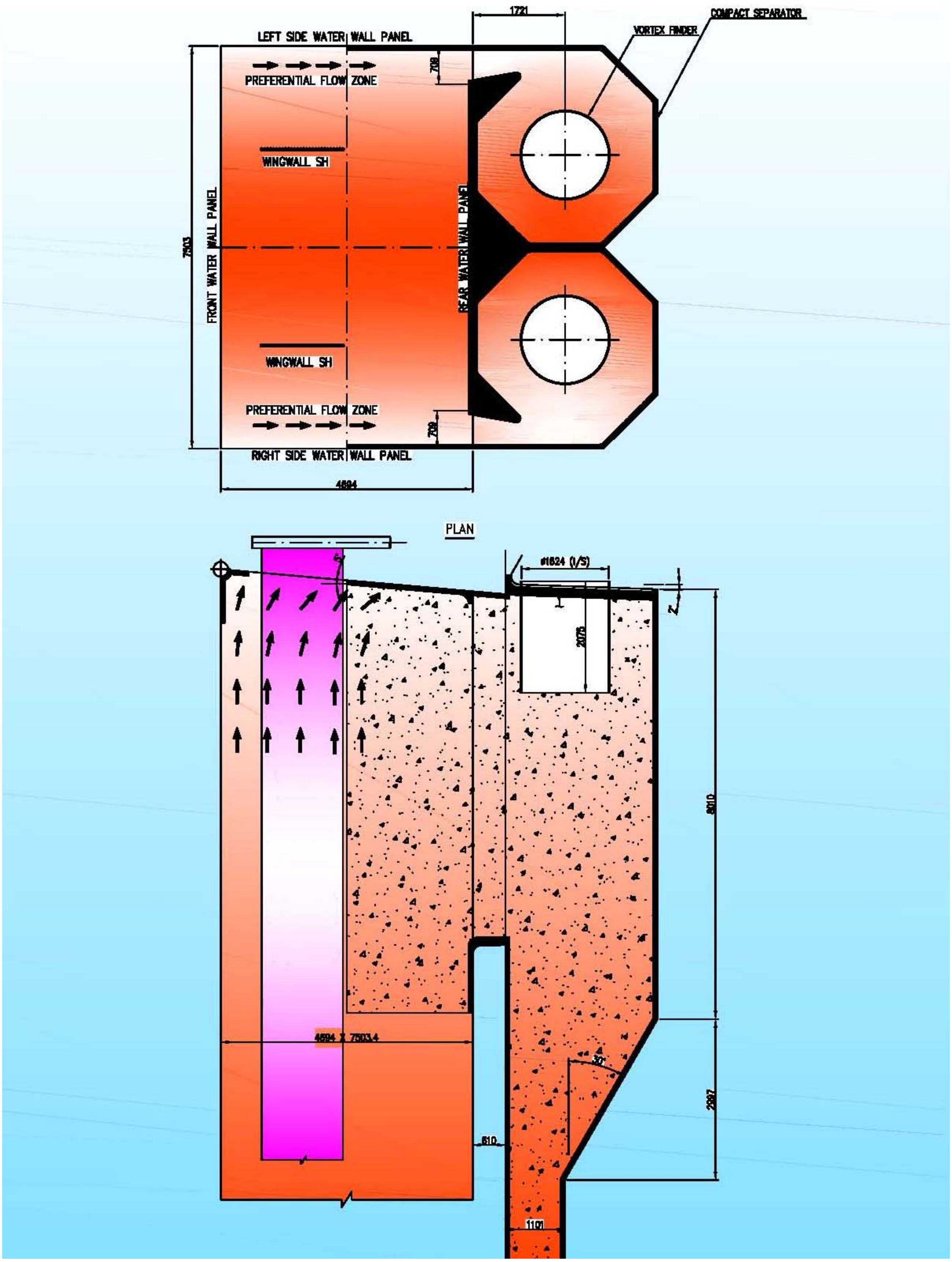
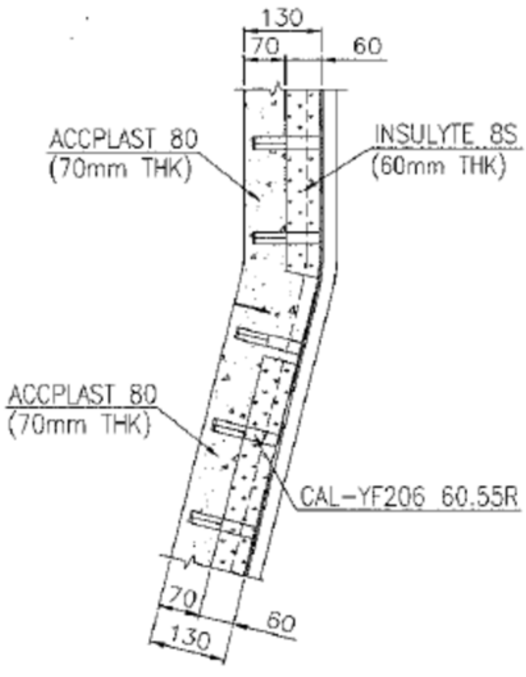


Figure 7: The top figure shows narrow entry to cyclone. The collection efficiency of this cyclone is good as the vortex is away from gas path. The internal recirculation of solids along the rear wall is expected to be more.


Photo 9 & 10: The left side photo shows the V type anchor welded to panel tubes. The refractory spalls off easily since the refractory thickness has to be at least 75 mm from tube crown. The right-side photo shows the studs design. This design is superior. The refractory repair is simpler. Thin layer of plastic refractory is found to be adequate during maintenance.



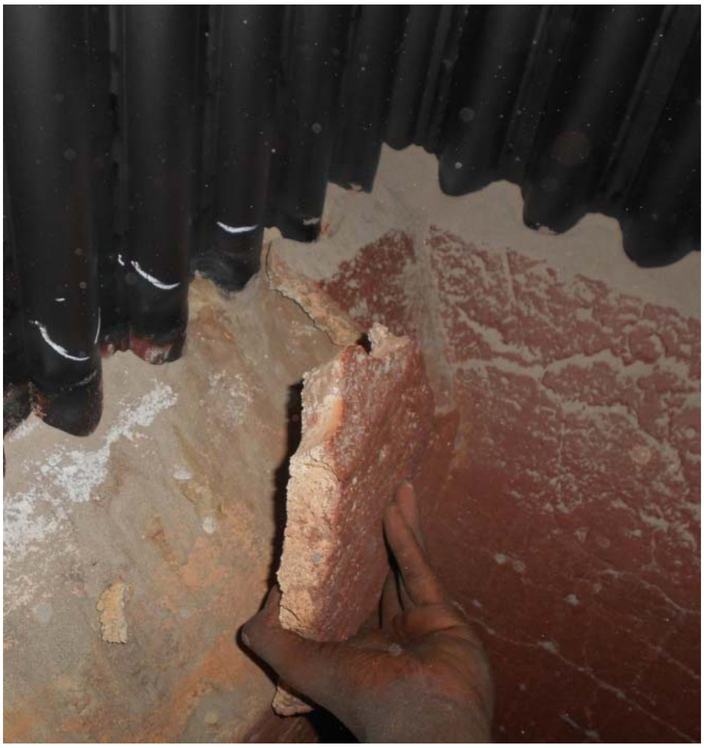


Figure 8 & Photo 11: The above refractory detail adopted by one manufacturer is the most complex refractory we have seen. The entire refractory had to be done all over again due to this poor design. The design is not suited for the quick thermal cycling / occasional high temperature excursions and large temperature swing during a tube leak. Tube leak is unavoidable. If it happens, the design should not demand total refractory rework. We find the stud design with 50 mm thick LC castable is found to be good. 10 mm thick plastic refractory overcoat is seen to be good enough during maintenance.

Photo 12 -14: Thick refractory in CFBC furnace walls is prone for spalling on account of thermal expansion. The air nozzles get eroded when the spalled refractory fall in between the nozzles and obstruct the air path as they get stuck near / at air nozzle openings. Air nozzle failures cause combustible bed material seepage in to the windbox. This is a serious hazard starting from simple refractory defects. Bottom photo shows the accumulation of bed material inside the windbox.

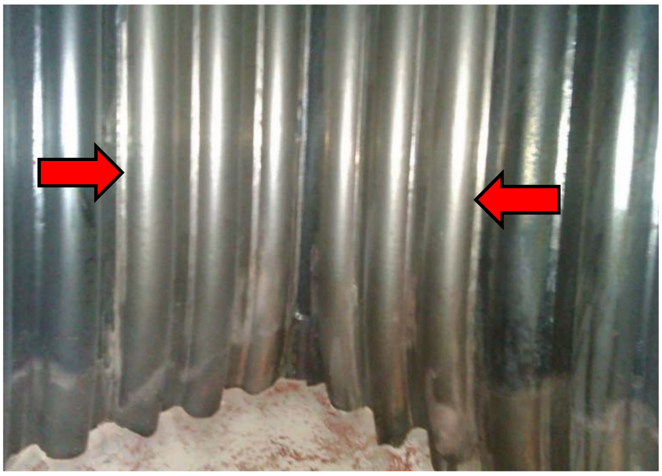



Photo 15 & 16: Both the photos above show erosion of corner tubes in CFBC boiler. The location depends on the load factor and the cyclone outlet configuration. In addition, the corners of CFBC boilers generally have defects on fin closures. By applying the corner refractory, the corner tubes can be protected. See figure 9 below.

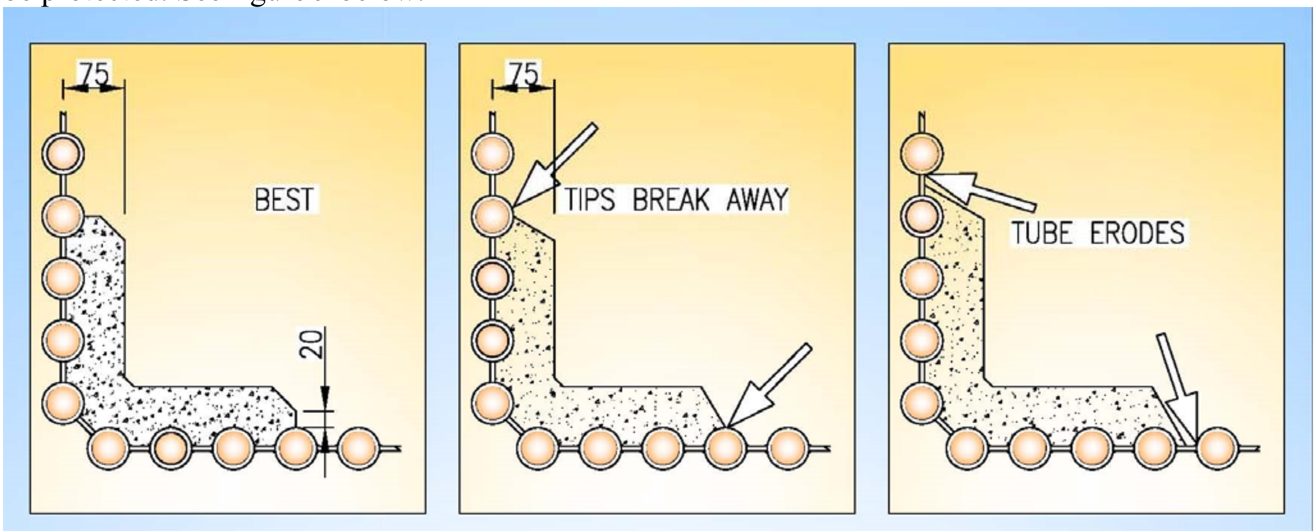


Figure 9: The above figures show the good & bad corner refractory details. Neither the designer or applicator do justice to this detail. Same manufacturer is seen to have supplied boilers with different refractory contours at corners.


Photo 17 & 18: While the CFBC boiler demands a corner refractory detail for protection from erosion, improper design, improper application cause localized erosion. Localized deep cuts are seen in places of improper refractory tipping. Metal filling is to be done to stop the growth of the cut.

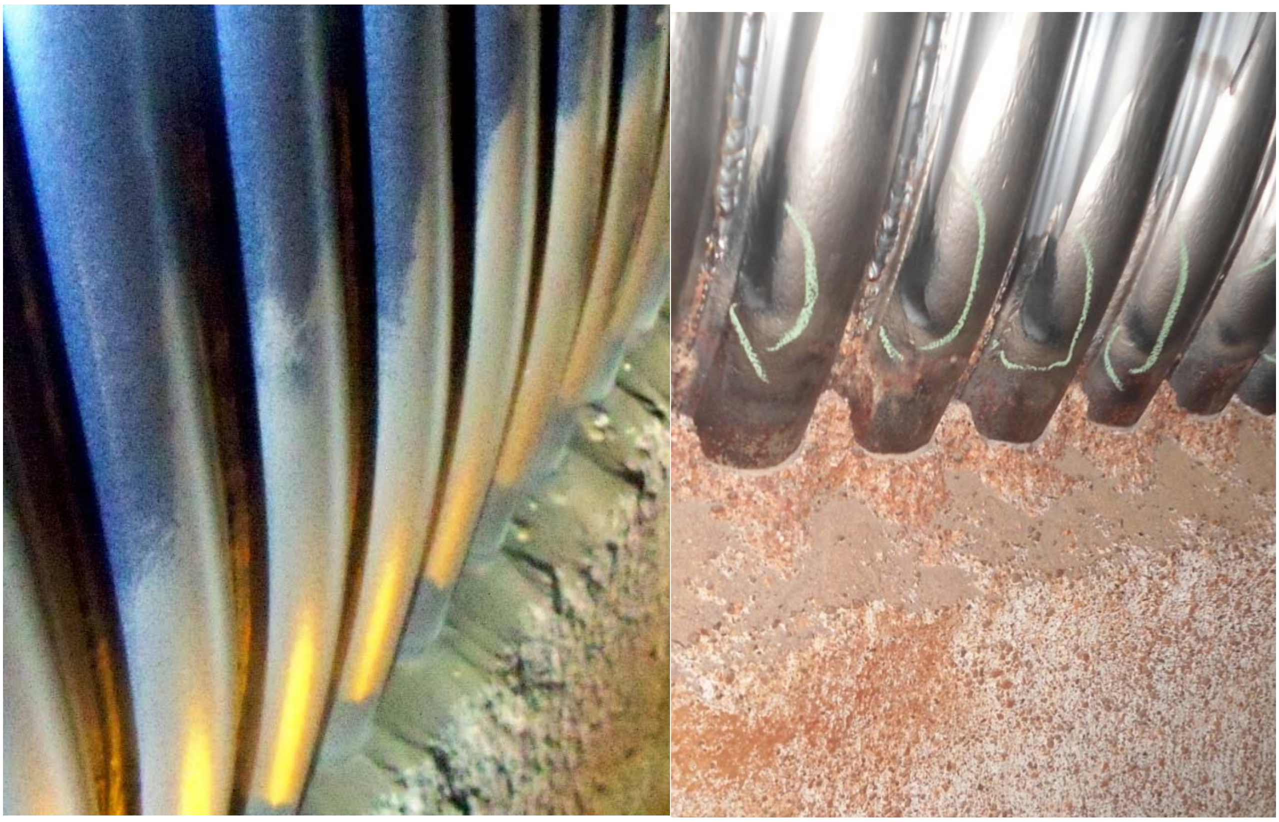


Photo 19 & 20: The above photo shows the erosion of excess refractory constructed at kick off zone. As the projecting refractory acts a brake for falling material, the tubes above get polished / eroded.

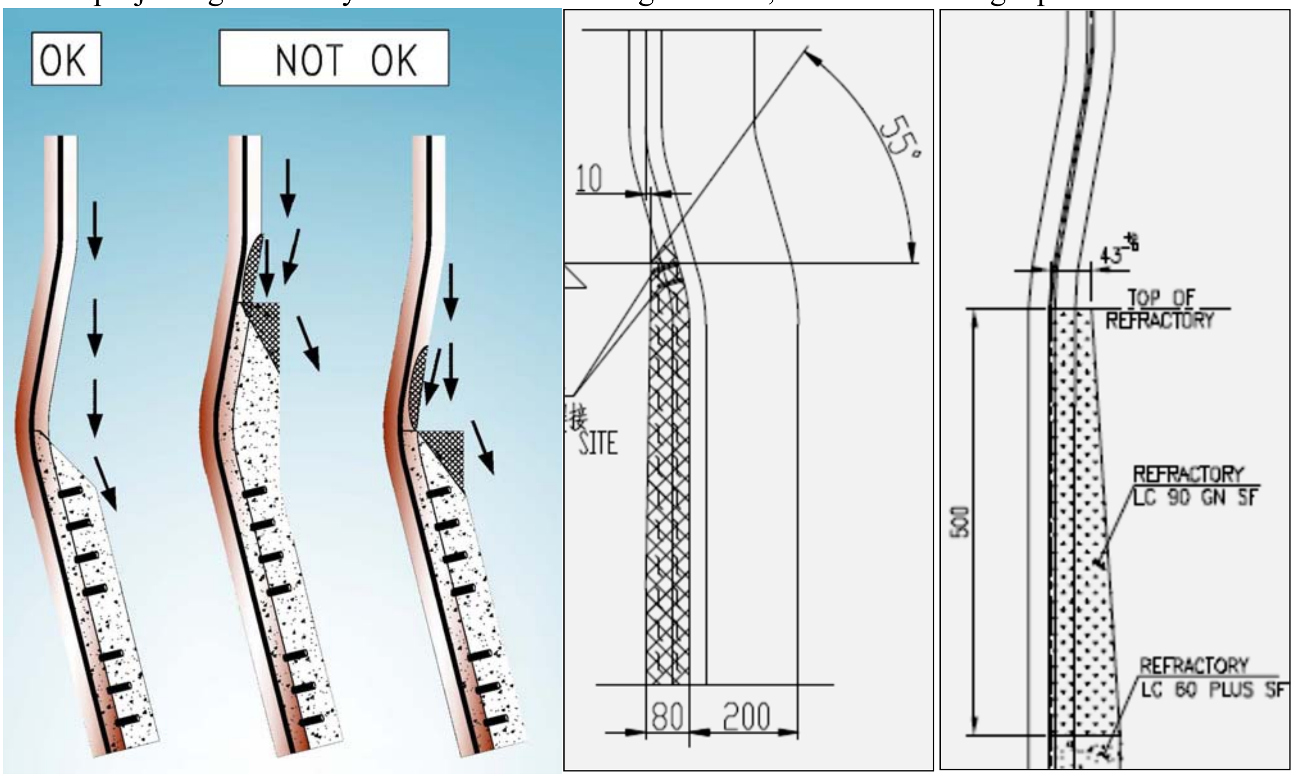


Figure 10-12: The above are the details of other boiler makers. If there is excess refractory, the waterwall at kick off zone erodes faster. The accuracy of construction is very important. The flow of solids should be free & unobstructed.

Photo 21 & 22: The above photos show poor practices by some boiler makers. Left side photo shows the inappropriate protection system. Right side photo shows the absence of studs to hold the refractory at the bends.

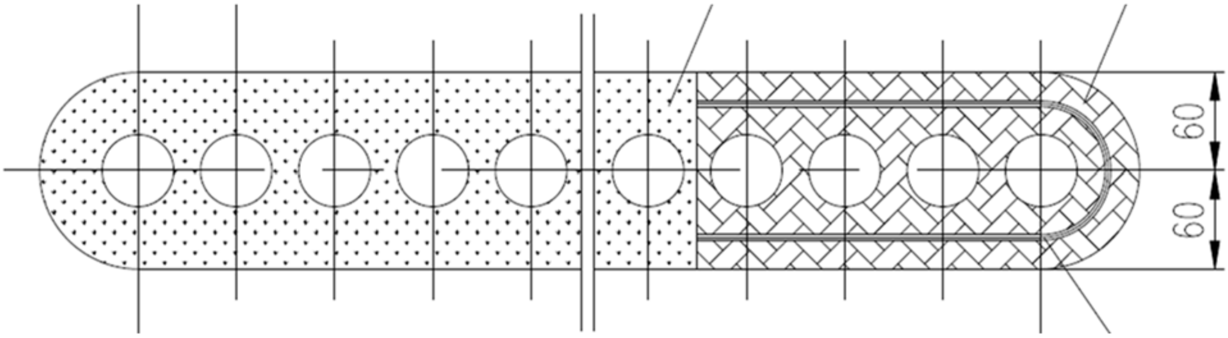
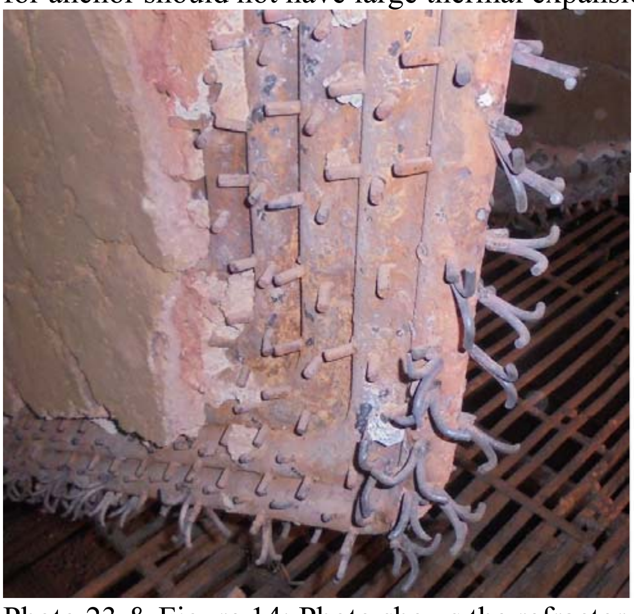


Figure 13: The above drawing shows the improper anchor design to hold the refractory. A steel used for anchor should not have large thermal expansion. If so the refractory would certainly break away.



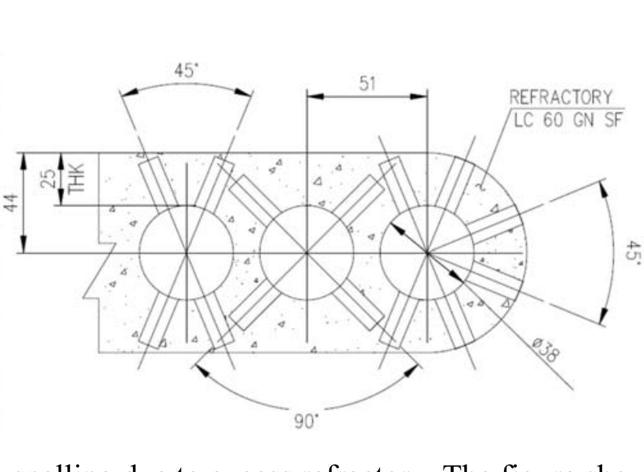


Photo 23 & Figure 14: Photo shows the refractory spalling due to excess refractory. The figure shows the refractory desirable fore erosion protection of the outer most tube of wingwall evporator / SH bottom / bend section. Long anchors are not required at all.

Manufacturing and erection notes for CFBC furnace panels:

1. Panel should be manufactured using automatic SAW machine or Automatic MIG welding machine.
2. All tube and fin buttwelds are to be flush ground smooth only on fire side.
3. After completing the fin to fin butt weld from outside, inside seal run to be done before grinding smooth.
4. No knots are permitted in the tube – fin welding. Weld should be uniform.
5. Tubes should be parallel and well aligned.
6. Panel shall be free of bow and twist.
7. Panels should be erected to plumb.
8. Diagonal distance of panels shall not deviate by more than 5 mm.

Figure 15: The above notes are the important ones for CFBC panel manufacture and erection at field. Note no 3 and 7 are specific to field work.

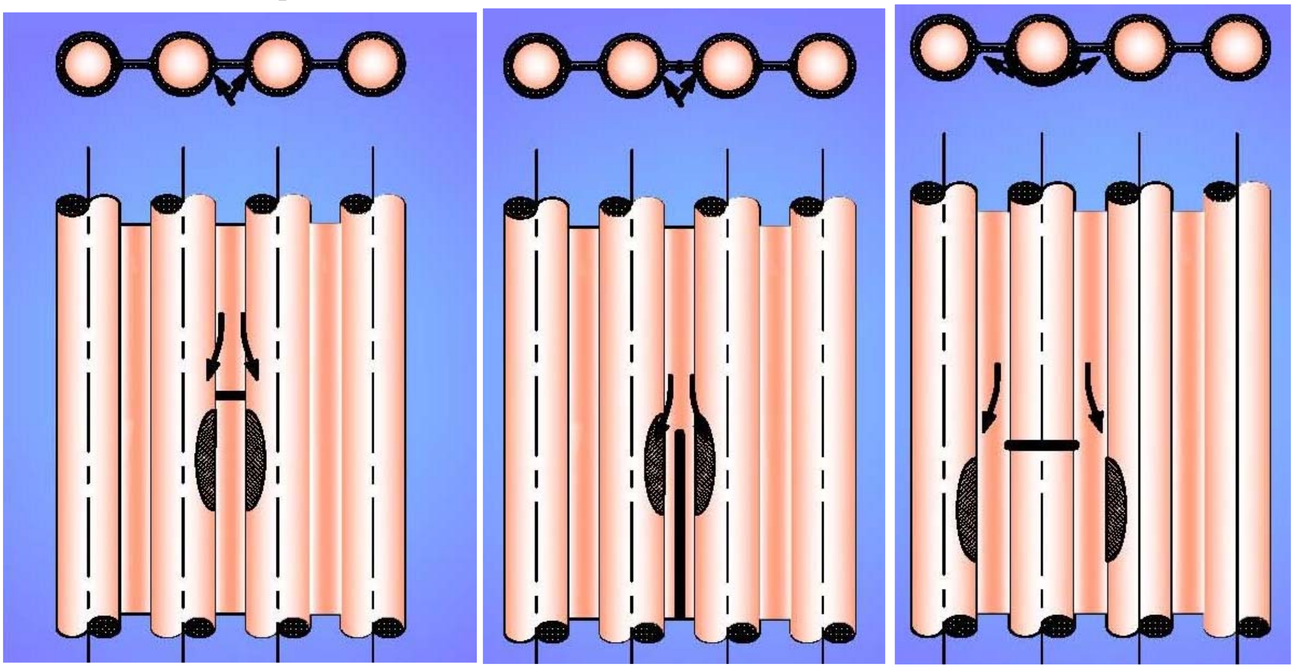


Figure 16-18: The above figures illustrate the flow of solids in CFBC furnace around the fin / tube butt weld projection. Tube leakges occur at the fin-tube weldment area only.

Photo 24: The left side photo shows the hapahzard erosion pattern experienced at tube butt / fin butt weld zone.

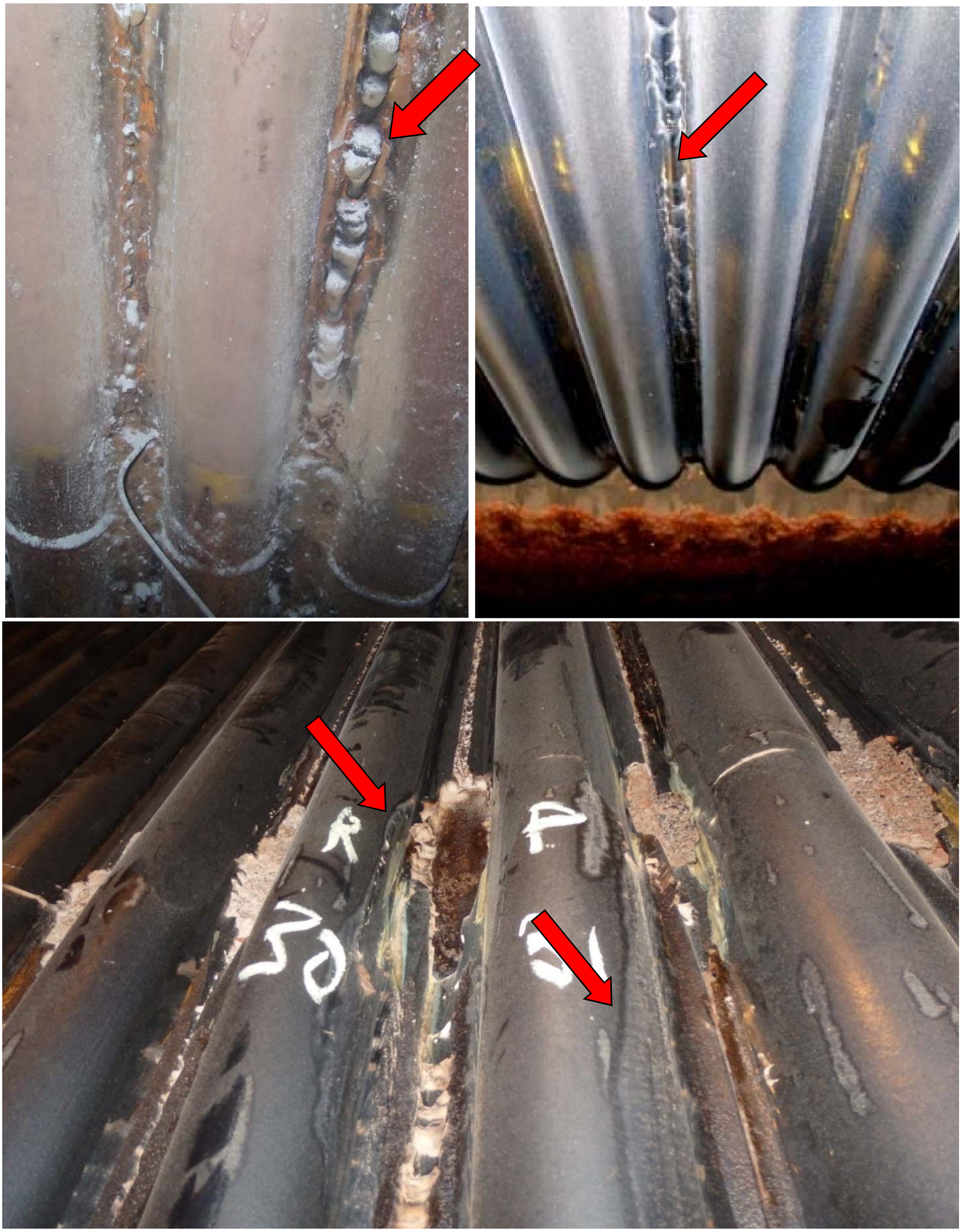


Photo 25 to 27 : The top photos show the no finish / poor finishing of fins leading to erosion of the tubes at the fin to tube weld zone. Many of the construction engineers or inspection engineers are not aware of this requirement. The main reason for this descrepancy is that no scoffolding is carried out to finish the welds on the fire side. Scaffoding or floating platform materials must be envisaged in the procurement stage itself.

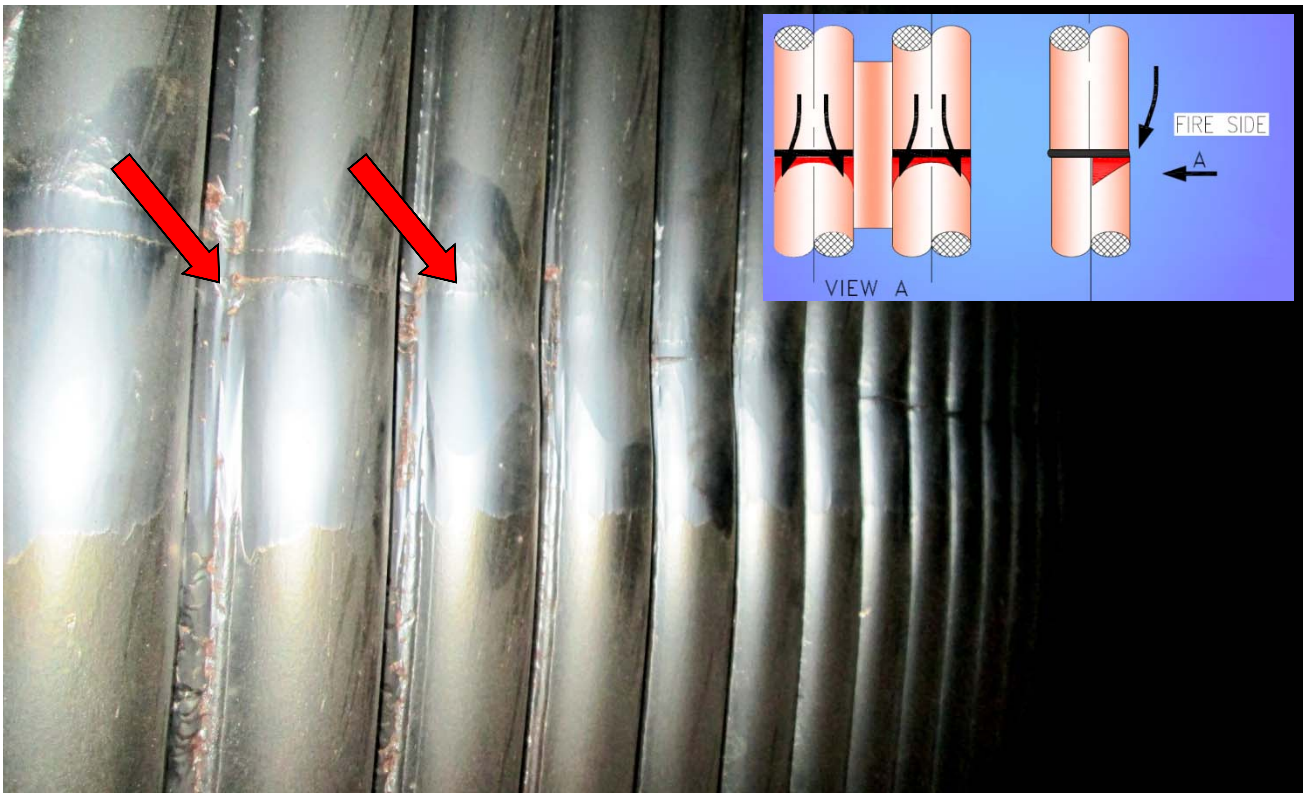


Photo 28 ; Figure 19: The top photo & figure show the erosion due to misalignment of tube at field joint. The tubes are eroded as the bottom panel tubes got displaced towards the fire side. Hence the solids moving down along the panel chop off the projected surface.

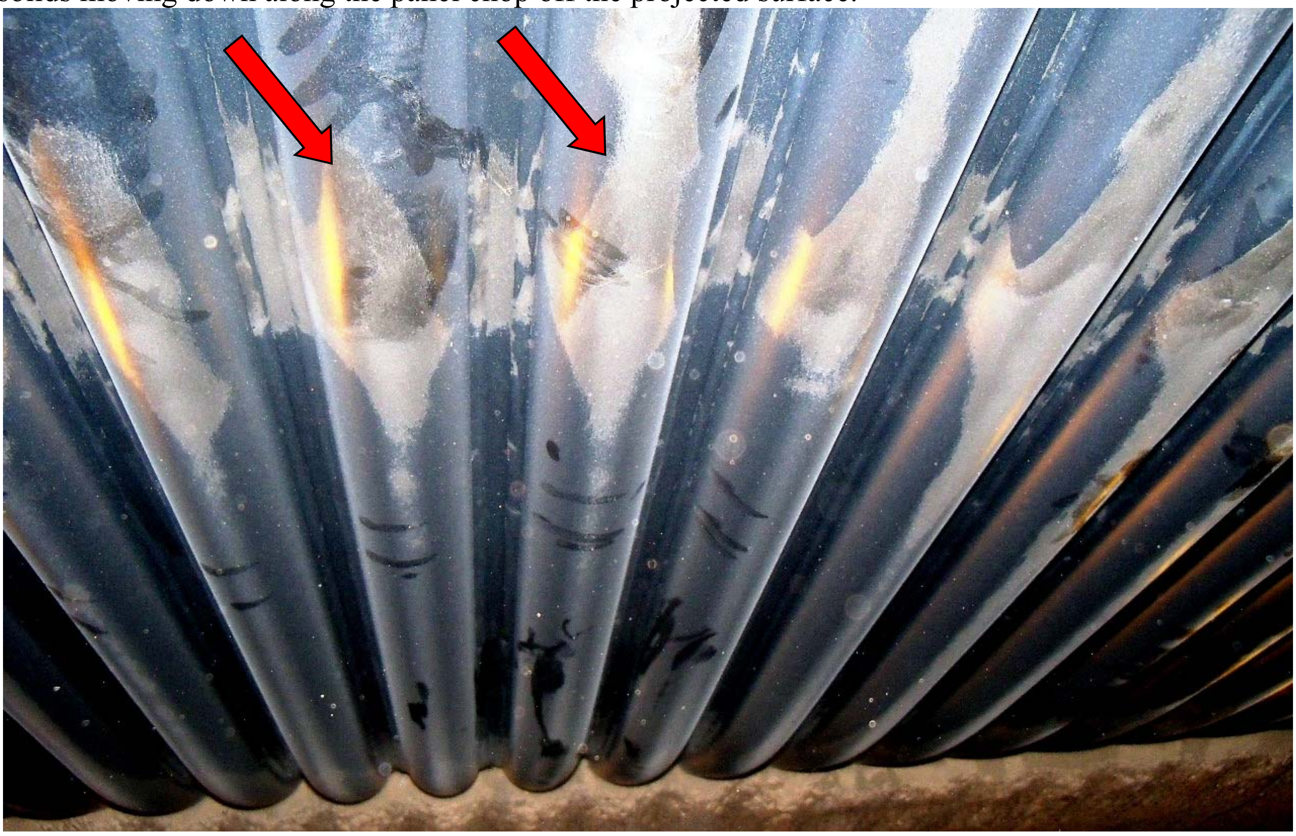


Photo 29: The photo shows the erosion of tubes when there is bow present in the panel. Improper handling and failure to ensure panel verticality resulted in the erosion of tubes at the bow zone.

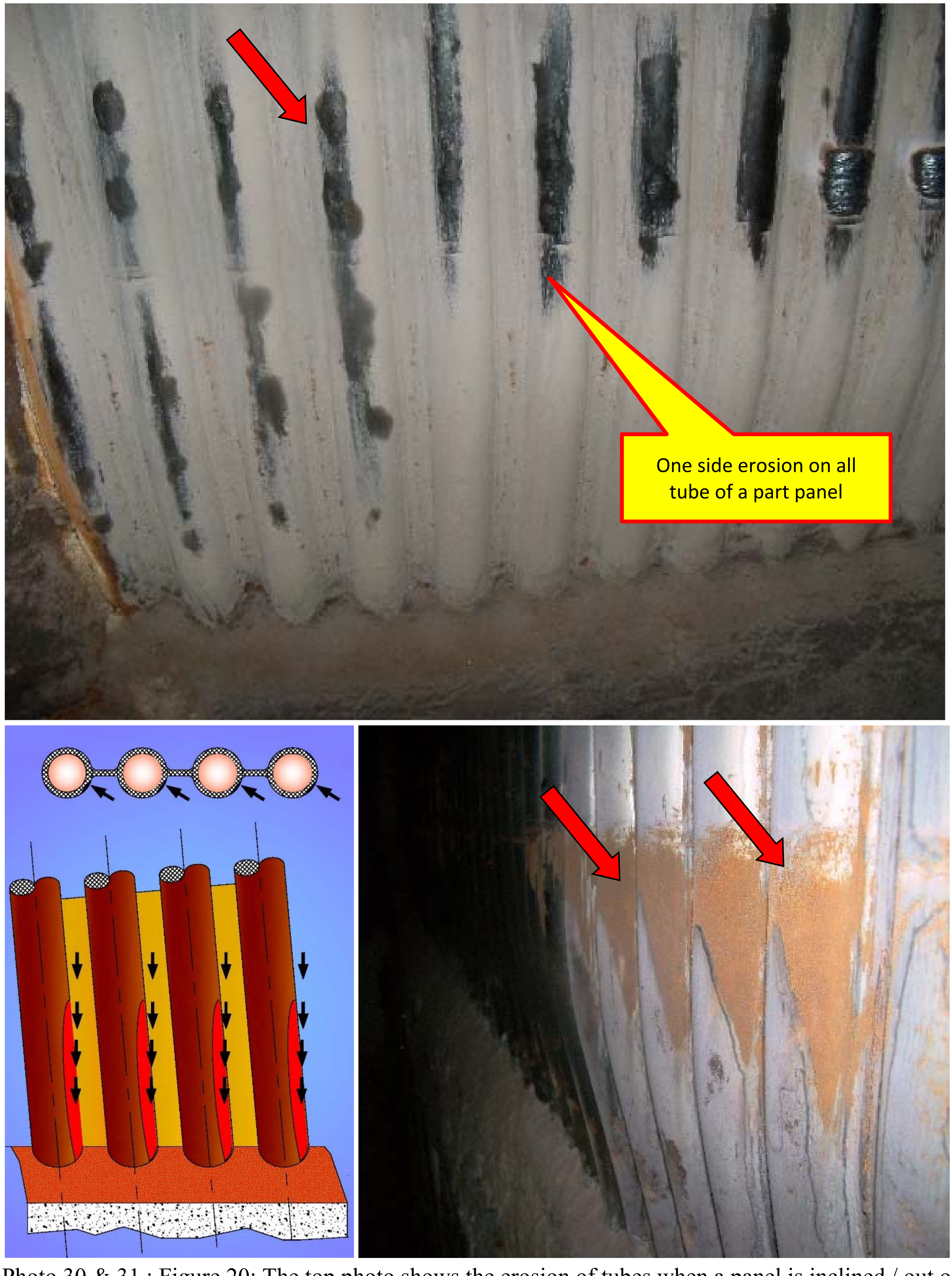


Photo 30 & 31 ; Figure 20: The top photo shows the erosion of tubes when a panel is inclined / out of verticality. Bottom photo shows the case of out of verticality of bottom panel at the field joint. The tubes are out of verticality. In the figure the erosion mechanism is illustrated.

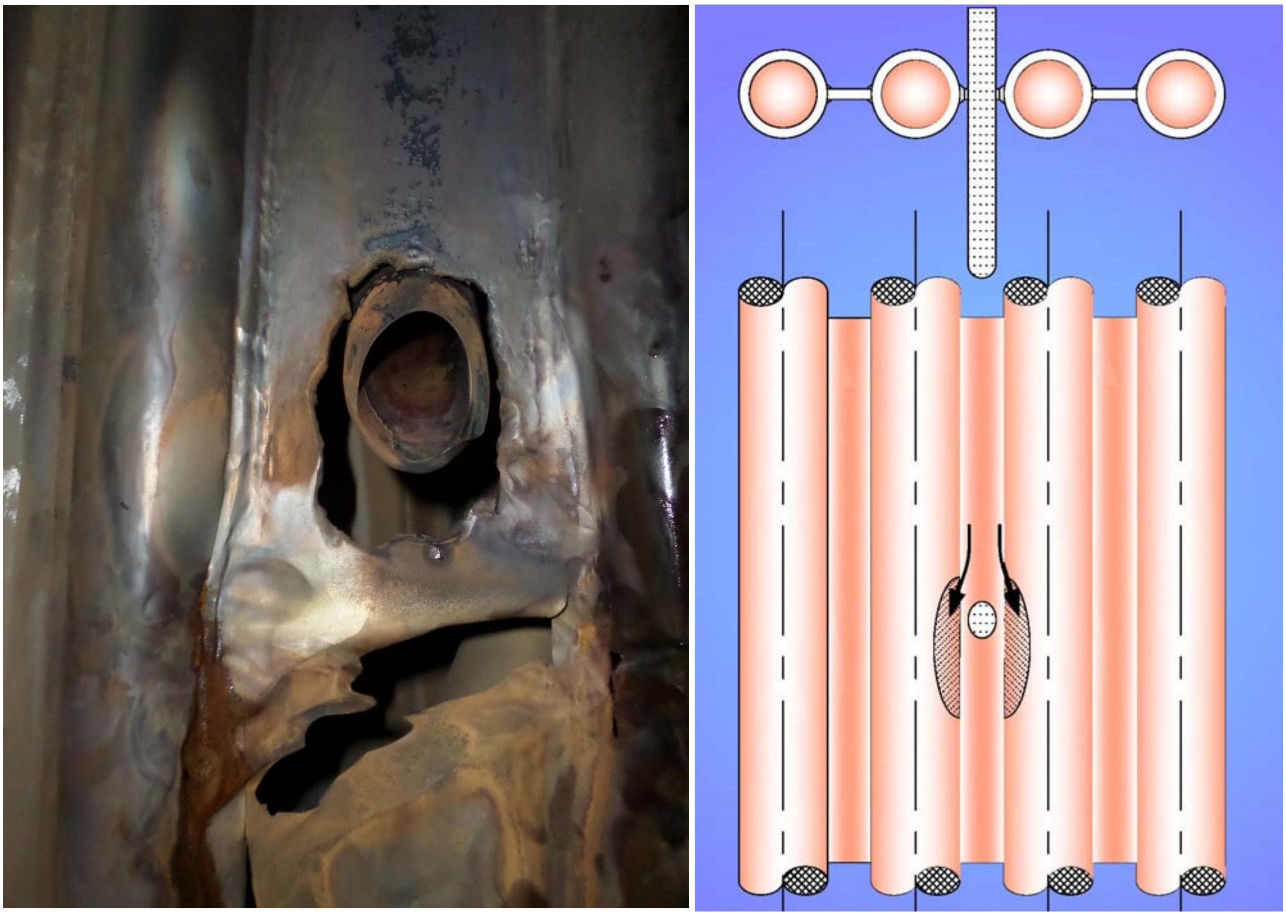


Photo 32; Figure 21: The top photo shows the erosion of tubes when there is a instrument tapping penetration in the panel. A thermocouple at mid of furnace is not required for CFBC furnace.

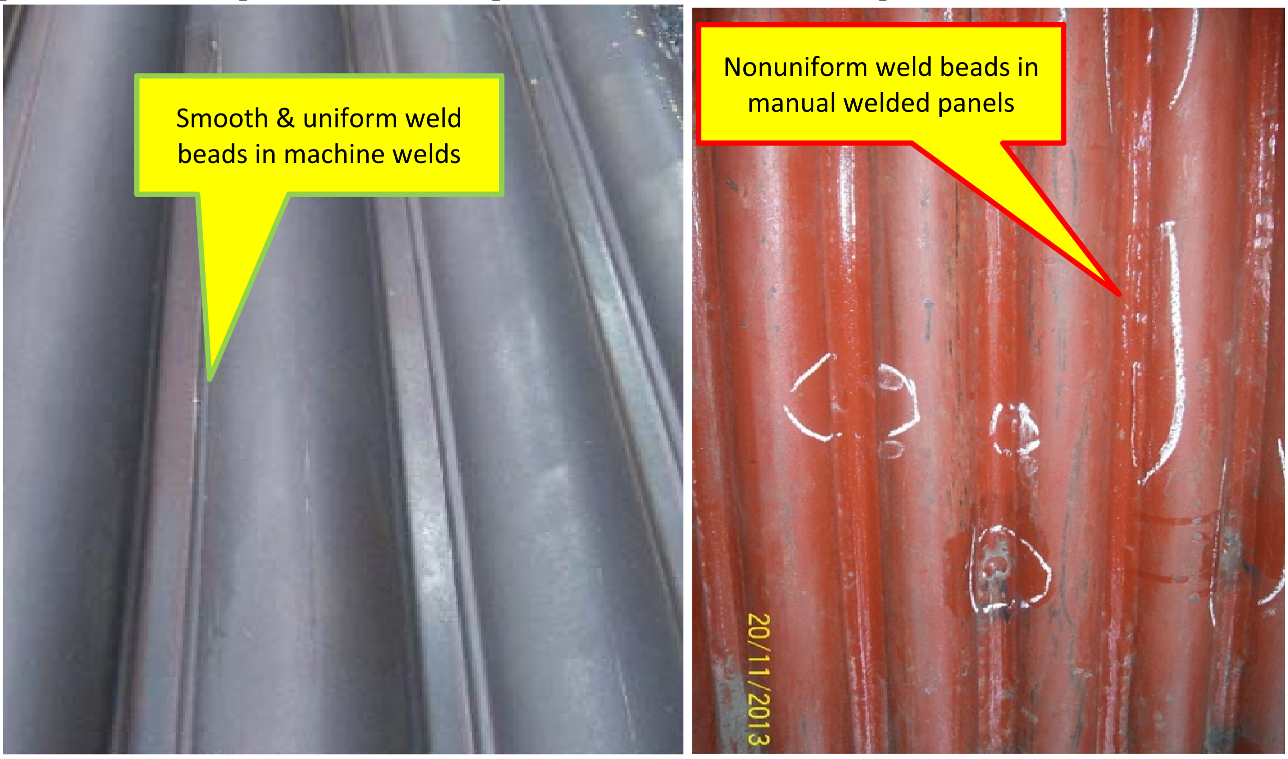
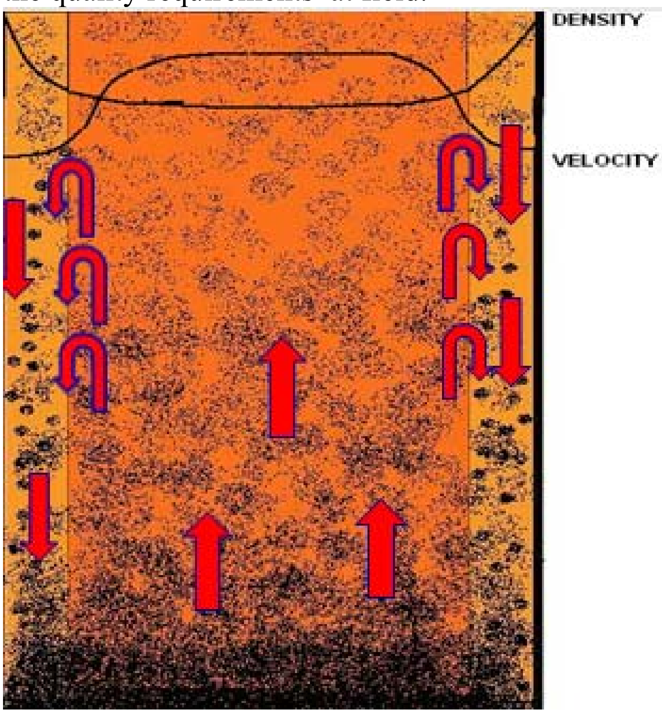


Photo 33 & 34: The difference between panels made by manual process and automat can be seen here. The nonuniform weld beads would cause localised erosion problem.

Photo 35: Photo shows the out of alignment of manually welded panel below the original machine welded panels. Boilers owners have to procure the spare panels only from parties who would delier the panels duly welded in mechanized welding machine. Panel replacement team should be clear about the quality requirements at field.



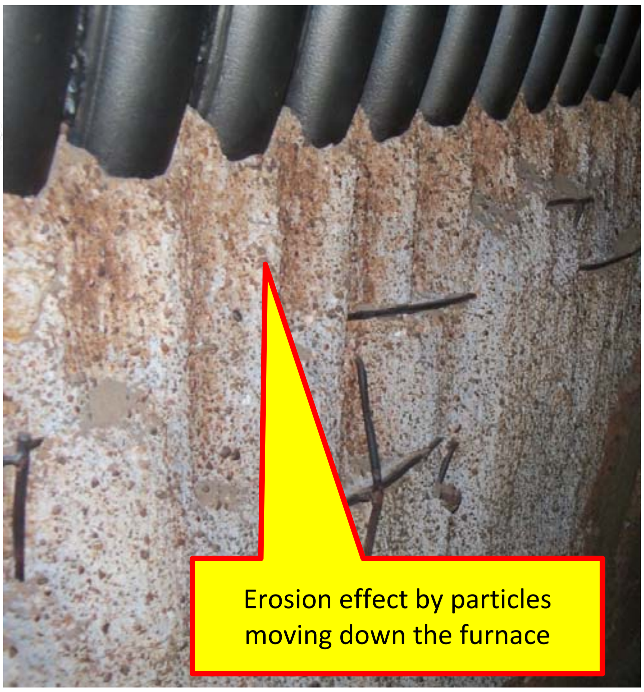


Figure 22; Photo 36: Figure shows the motion of solids in CFBC furnace. The density of solids is high near the wall & highest along the corners. The gas velocity along the wall is lesser. Some particles combine forming clusters. They flow in the passage created between the tubes along the fins. This can be inferred by the erosion pattern of the refractory at kick off zone. It is therefore calls for replacement of the furnace wall panels to a length of 5 m above the refractory over a period.

Photo 37 to 39 :Metal spray itself develops a mechanism of erosion. Coating peels off causing a inverted V or V cut in the panels. These photos are from unit which had operated for 3 years before failures became frequent. The first supply from manufacturer had this quality issue. Any field application may not give a satisfactory result. It is sensible to use plain water wall panel.

Photo 40 & 41 :Photos show the distortion of the vortex finder in two different boiler. Vortex finder gets distorted when there is a tubeleak at roof tube or in upper furnace walls or even at the water cooled cyclone. The sudden quenching of hot surface with water leads to unpredictable distortion. Continuing with distorted vortex finder alters the gas flow pattern at the furnace and cause preferntial erosion.

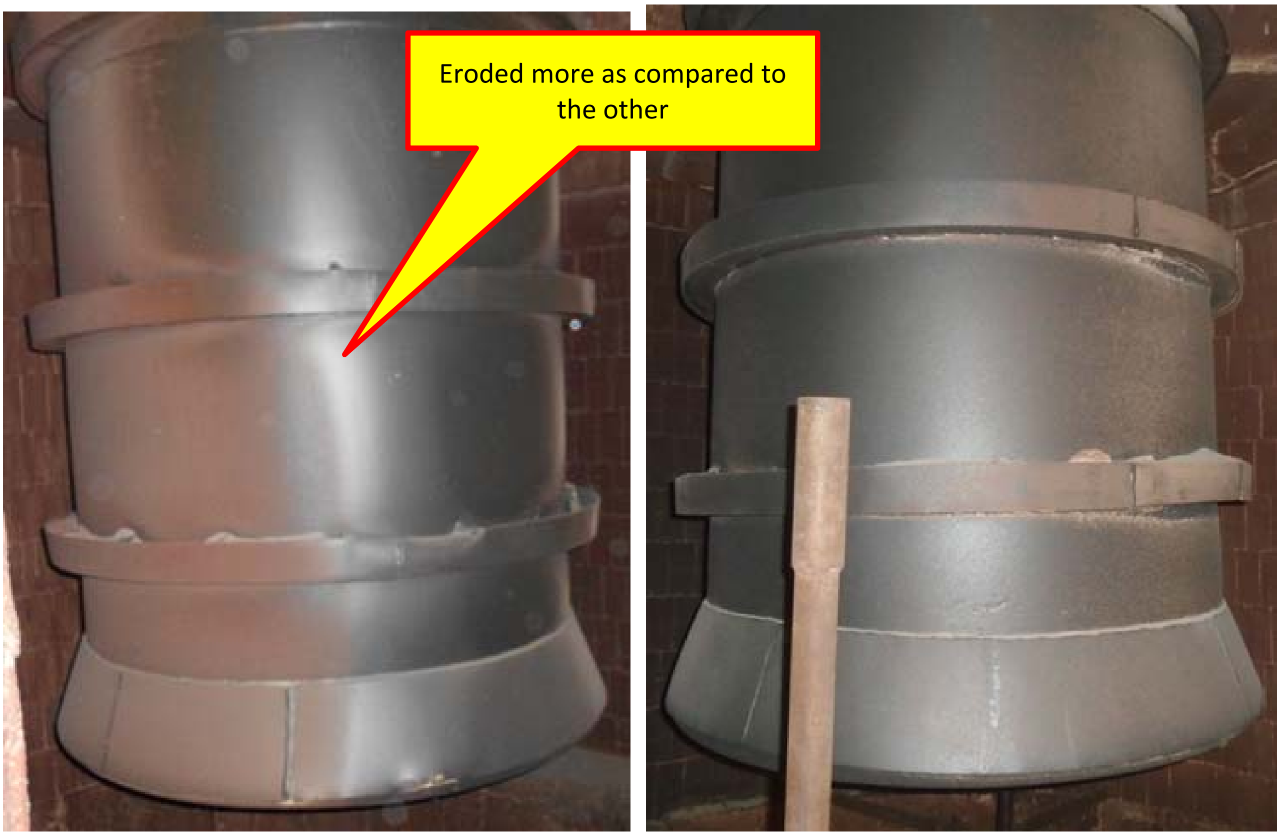


Photo 42 & 43: Photos show the difference in polishing between two vortex finders of same boiler. The collection at loop seal was found to be different. The refractory erosion was found to be different. Altogether there had been less upper furnace inventory in this boiler due to radial entry to cyclone. There had been difference in cyclone entry openings and shape. This is a case of refractory cyclone. When there is a difference in the cycone and it entry formation, differential gas flow would be present.

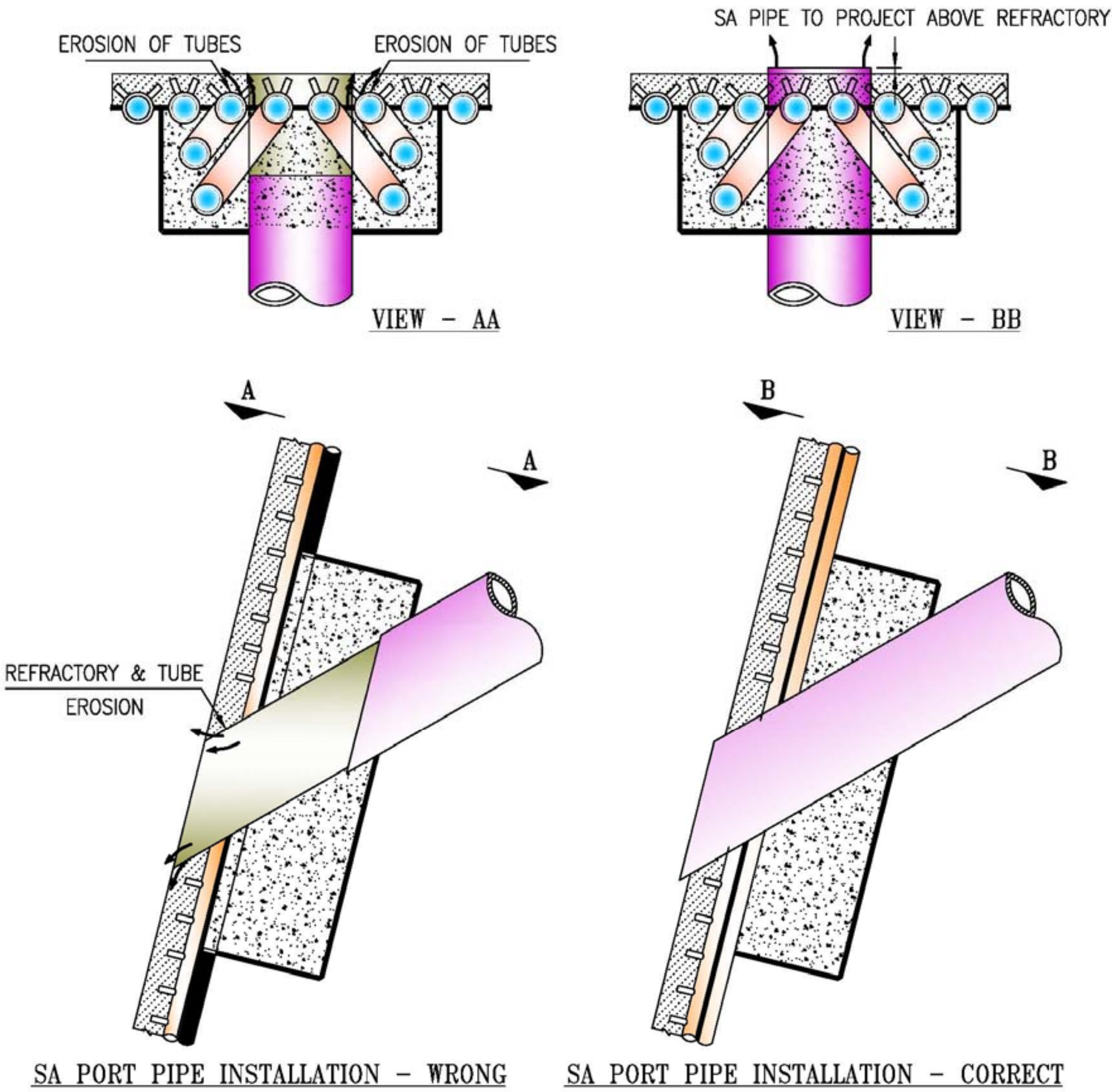
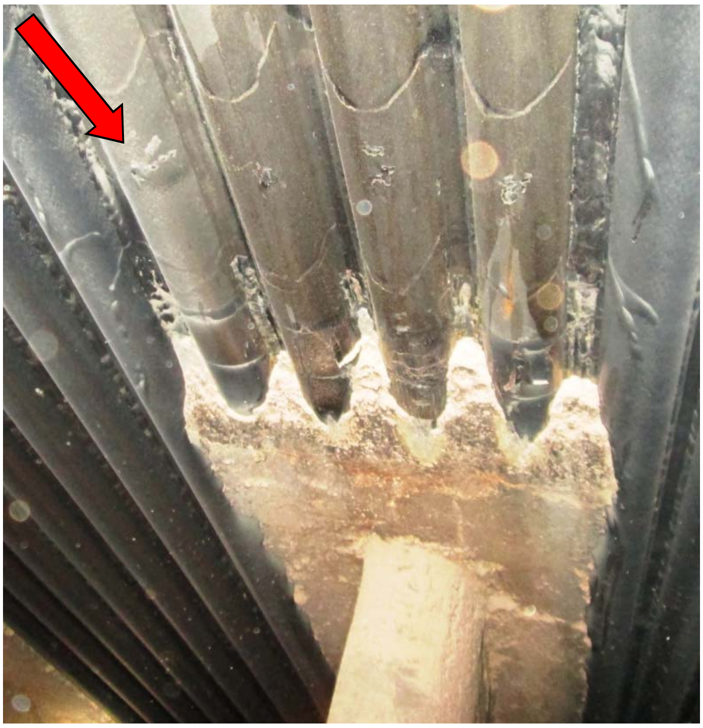


Photo 44 & 45 ; Figure 23: Photos show the erosion of tubes adjacent to SA port. Distortion of SA port pipe can happen due to wrong material selection of the port / if the minimum air is not maintained during operation. When there SA port pipe is not properly installed / if the refractory is not constructed properly, then also the tubes neraby the SA port would erode. In case SA port is not projrected beyond the furnace tube, the refractory spalling can cause direct erosion of tubes.



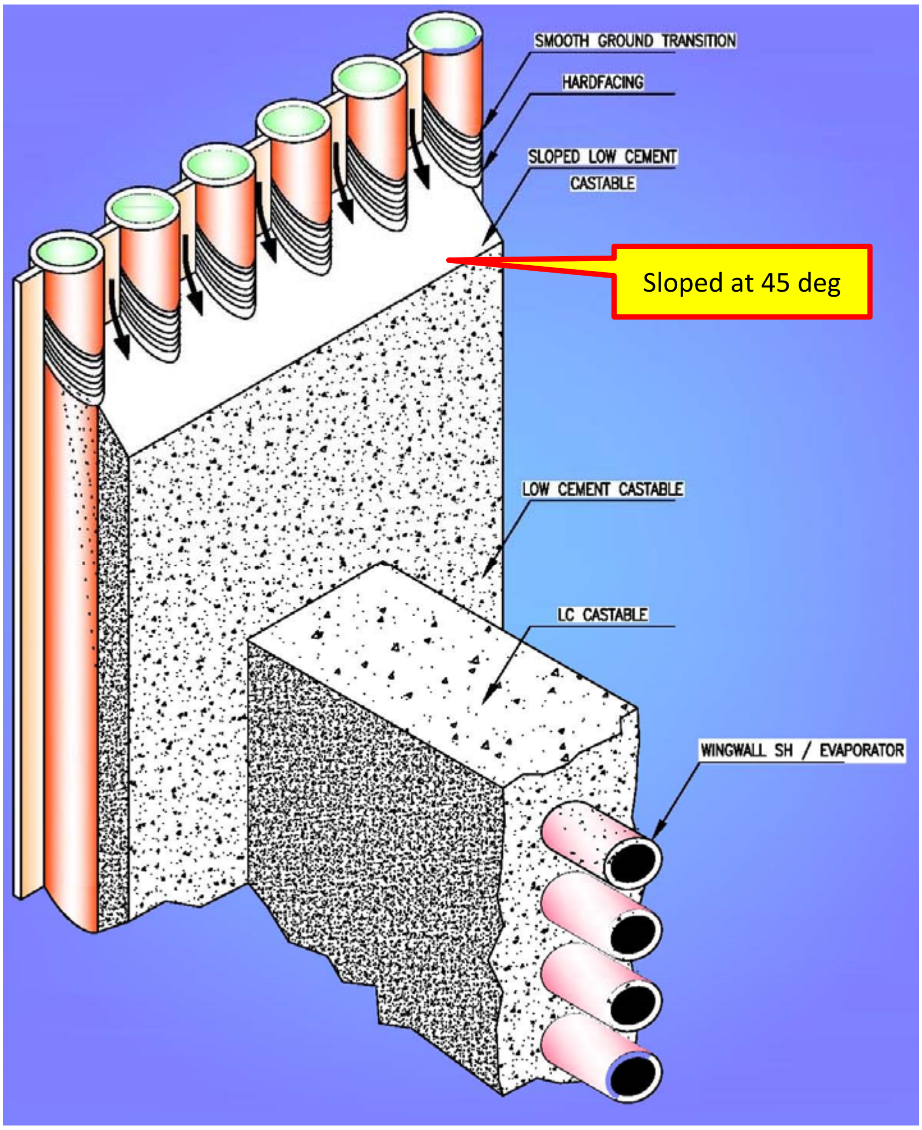


Photo 46 & 47; Figure 24:

- Photos above show the possibility of moustache erosion along the refractory to tube interface. The figure illustrates the solid flow which cause localized erosion of tubes.
- Weld overlaying is adopted here. HVOF metal spray can be adopted only if proper working conditions are made available.
- Metal spray or weld overlay is required for 200 mm length. The overlay should be completed before applying the refractory since a 50-mm overlap is a must between refractory and the overlay.
- The sloped refractory face is important to reduce the erosion rate. The contouring of refractory along the tube is important as required for furnace corner refractory.

Photo 48: Photo shows the peeling of the HVOF spray over the wingwall evaporator panel. Field repair is not successful, unless it is executed with complete removal of previous coating.

Photo 49: Photo shows the repair of weld overlay zone in wing wall SH. The mistake here is that the refractory should be sloped at 45 deg to allow free flow of solids without much resistance.