Investigation of repeated economiser tube failures of a 135 tph cold cyclone CFB boiler – a case study

There were quick and successive failures of economiser tubes in a four years old cold cyclone circulating fluidised bed 135 tph boiler in a short span of three months. Advance inspection and failure analysis, change in operational practices were used to get the boiler running at full load at the earliest possible time. This paper presents details of the process of inspection, maintenance, operation and failure investigation carried out for the economiser tubes of the boiler. The failure of the economiser tubes was due to external corrosion of the tubes furnace fire side due to presence of sulphur in coal, accompanied by localised erosion by high levels of alpha-quartz in coal ash.

Keywords: *Economiser, tube failure, cyclone, CFB boiler, mechanism.*

1.0 Introduction

Boiler tubes are subject to a wide variety of failures involving one or several mechanisms. Forced outage of a boiler caused by various reasons but, about 50 to 60% of the total outage can be attributed to tube failure. The main component of a modern water tube boiler consists of tubes and pipes of various specifications and orientations to suit the design requirements contingent upon the flow and heat transfer characteristics backed by well improved latest design and construction, automatic control and any safety systems, is still prone to generation loss due to tube failures.

Most prominent mechanisms those lead to boiler tube and other pressure parts failures are corrosion including pitting and erosion, mechanical environmental processes including stress-corrosion cracking and hydrogen damage, fracture including fatigue fracture, thermal fatigue and stress-rupture and distortion involving thermal - expansion effects or creep. The root causes of failure can generally be classified as: (a) Design defects; (b) Defects caused by weakening of the structures; (c) Improper operation; (d) Poor maintenance and inadequate water treatment and (e) Miscellaneous causes. Most of the failures of a steam generating plant occurs in the pressurised components, that is, the tubing, piping and pressure vessels that constitute the steam generating portion of the system. Weakening of the structure can be divided into three somewhat overlapping categories: (1) Weakening of pressure parts; (2) Failure of supports; (3) Mechanical damage. The various conditions that may cause weakening of boiler pressure parts viz. overheating, loss of metal due to corrosion, weakening of the furnace wall because of improper combustion or flame impingement and soot blower erosion can be considered in the context of tube failures.

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2.0 Brief description of boiler system

2.1 Cold Cyclone CFBC

Boiler offers valuable solution to reduce pollution. Salient advantages are: (a) Fuel of different types/origin and quality can be burnt at high efficiency. (b) Sulphur dioxide, hydrogen chloride, hydrogen fluoride released during combustion is retained in the ash with the help of limestone. (c) Due to low combustion temperature and combustion in stages, there is only a little development of NO_x. Flue gas cleaning systems are not necessary and thus eliminate additional efficiency losses. Lower NO_x formation helped by staged firing cold cyclone.

2.2 Water and steam circuit

Feed water is supplied to economizer-I via feed control station. Economizer-I is located in upper portion of second pass and interconnecting piping takes feed water to inlet header of economizer-II in upper portion of combustor. Drum receives feed water from economizer-II. Drum is connected to bottom headers of combustor via down comers and supply pipes for feeding water. The furnace walls headers located in upper portion of combustor convey mixture of steam and water to drum through riser tubes. As the water in furnace walls rises, its place is taken by denser/colder water from down comer through natural circulation and continues. As the water-steam mixture flowing upwards through furnace tubes, top water wall headers and risers enters the drum, separation of steam from water takes place. Steam from drum flows to saturated steam header located slightly above the steam drum. Steam then flows through superheater-I, superheater-II and superheater-III absorbing the heat from outgoing flue gases of combustor. In economiser-I, flue gases from cyclones flow downwards towards air heater whereas the feed water moves upwards. The economiser coils are suspended from steel structure. Economiser-I is counter-flow type heat exchanger and of plain tube configuration. The flue gases flow upwards through gaps between economiser II coils. The water also moves upwards to economiser outlet header. Feed water flows from economiser-II outlet header to drum through nozzles with thermal sleeves. Inside the steam drum, perforated feed pipes ensure even distribution of feed water. Economiser-II is parallel-flow type heat exchanger and of plain tube configuration.

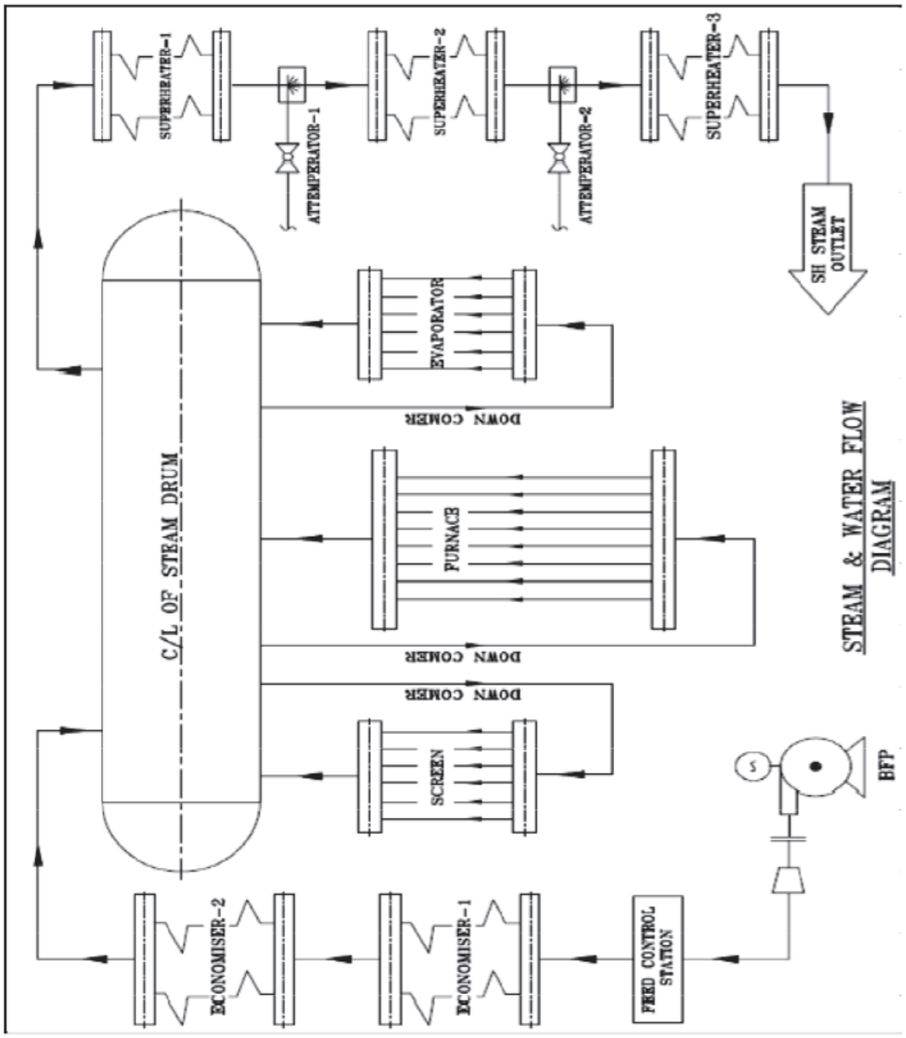

Fig.1: Schematic diagram of water and steam circuit

2.3 Combustion Air and Flue Gas System

The combustion air required for the fluidised bed combustion is admitted from primary air fans and secondary air fans, and supplied to the furnace. The airflow is adjusted to the respective requirement through speed control for PA, SA & ID fans. Individual suction ducts of each PA and SA fans direct the fresh air to the respective fans. Discharge side ducts of both PA fans are joined together to form a single duct entering air preheater. Primary air (PA) and secondary/ tertiary air (SA/TA) flows through the tubular air preheater in 2 stages. This splits up into combustion air and dilution air. The primary air is blown into the fluidised bed via PA nozzles. Generally, primary air is routed through combustion air, and dilution air during cold start up. Secondary air is further split into secondary and tertiary air ducts with isolation/control dampers after air preheater. The secondary air is injected into the boiler by means of nozzles located above the fluidised bed. The tertiary air is supplied to the boiler through nozzles, located above the secondary air nozzles.

2.4 Flue gas path

The flue gas-side pressure in the free board, above the fluidised bed is around (-) 30 to (-) 50 mm WC. From here, the fly ash charged flue gases from combustion are conveyed to induced-draught fan. In the first pass of boiler, flue gas passes over screen, the final-stage i.e. superheater-3, superheater-2, superheater-1, evaporator and econimizer-2 reaching the second boiler pass via cyclone separators. The cyclone separator re-circulates the ash discharged from the fluidised bed a number of times. Approximately 95-97% of the ash contained in the flue gases is being separated in the cyclones.

2.5 Cyclones

The cyclones are of a self-supporting plate constructional design complete with wear protection. Ash laden flue gas enters from combustor exit into cyclones. The raw gas passes via the raw gas duct into the raw gas spiral. At this entry, the flue gas is centrifugally deflected. Due to the centrifugal forces the ash particles are flung out from the gas flow towards shell of cyclone. They overcome the flow resistance, which is caused by the sinking flow to the immersion pipe inlet. At the cyclone shell, the ash moves downwards into the stand pipes and finally in the siphon. The clean gases leave the cyclone via a centrally arranged immersion pipe. There are two cyclones in the boiler placed in front side. Ash collected in cyclones are re-circulated back into the furnace via siphon. There are two siphons in the boiler in the front side of boiler. In the second pass of boiler, the flue gases pass through economizer-1 and

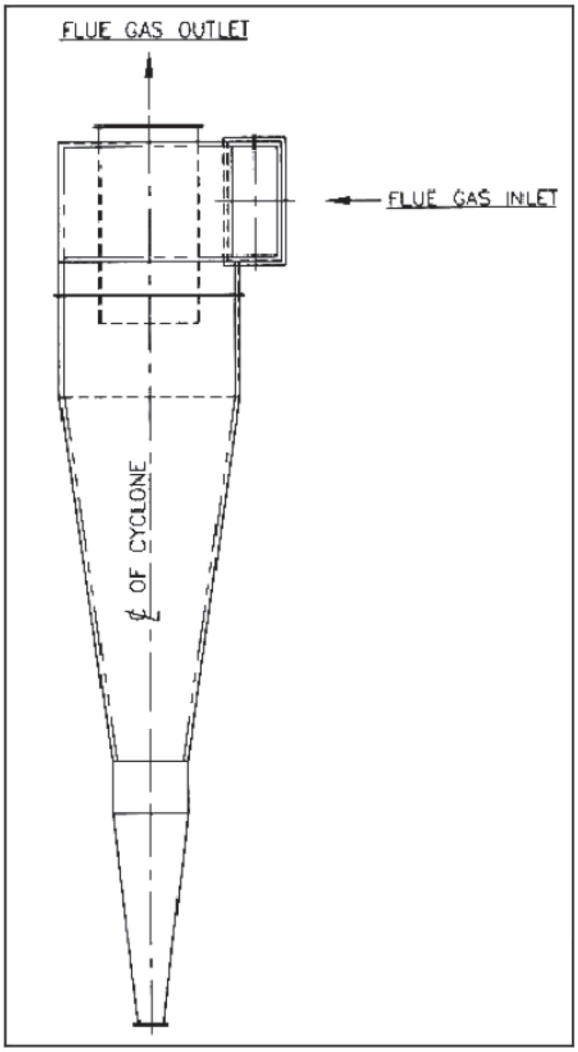

Fig.2: Sketch of cyclone

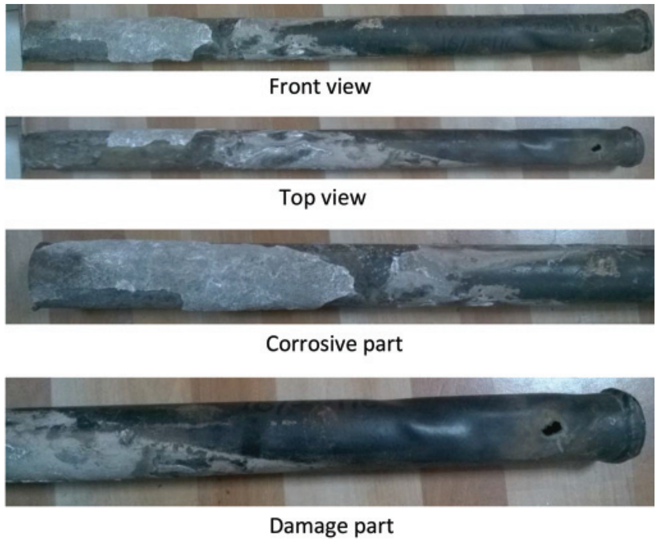

Fig.3: Failed economiser tube 1

Fig.4: Failed economiser tube 2

then the tubular air preheater. The primary air and secondary/ tertiary air are heated here.

3.0 Brief description of failure

The boiler had tripped on low drum level caused due to water leakage from the economiser tube. On opening the boiler cyclone side economiser manhole, the chamber was found with water. Economiser tube facing the fire side of the chamber was found leaking. Two of the tubes were found ruptured opened up and two tubes were found with pinhole leak. Though damaged tubes were found with sticking ash, any significant bulging of tubes was not observed. The following figures and tables contain the analysis conducted on the two failed service-exposed economiser tubes. The primary objective is to find out the reason for failure of the citedtubes.

Tube components studied

(a) Sample-1 : Failed service exposed economiser tube ‘1’ (43 MW unit CFBC unit 135 tph)

(b) Sample-2 : Failed service exposed economiser tube ‘2’ (43 MW unit CFBC unit 135 tph)

Procedure: For failure analysis and health assessment study: (a) Visual inspection; (b) Dimensional measurement; (c) Chemical analysis (supplied by client organisation); (d) Any other parametric analysis necessary during the course of investigation was done.

Technical information provided: (i) For economiser 2 Tubes: (a) Material specification of tubes: SA 210 A1; (b) Nominal dimensions: OD=38.1mm thickness=4.0 mm; (c) Working temperature: Tube 450°C+30°C; (d) Working pressure: 96.7+0.5 kg/cm^2

Visual inspection of leaking economiser tubes: Dimensional Measurement: Wall thickness assessments through outer diameter (OD) measurements using vernier caliper were carried out on the two tubes. The results are self-explanatory and shown in Tables 2 and 3.

Table 1: Avg. proximate analysis (CFBC)

Particulars	Coal	Char	Feed Fuel	Avg. Sieve analysis of mixed fuel CFBC)	
				+7mm(%)	2.02
				+6mm(%)	2.50
SM %	6.00	7.91	6.98	+5mm(%)	4.04
IM %	2.04	1.07	1.55	+4mm(%)	8.28
ASH %	46.84	70.31	58.44	+3mm(%)	7.22
VM %	22.46	6.28	14.53	+2mm(%)	14.63
FC%	28.66	22.34	25.48	+1mm(%)	19.92
GCV(K.CAL/KG)	3521	1640	2631	-1mm(%)	48.61

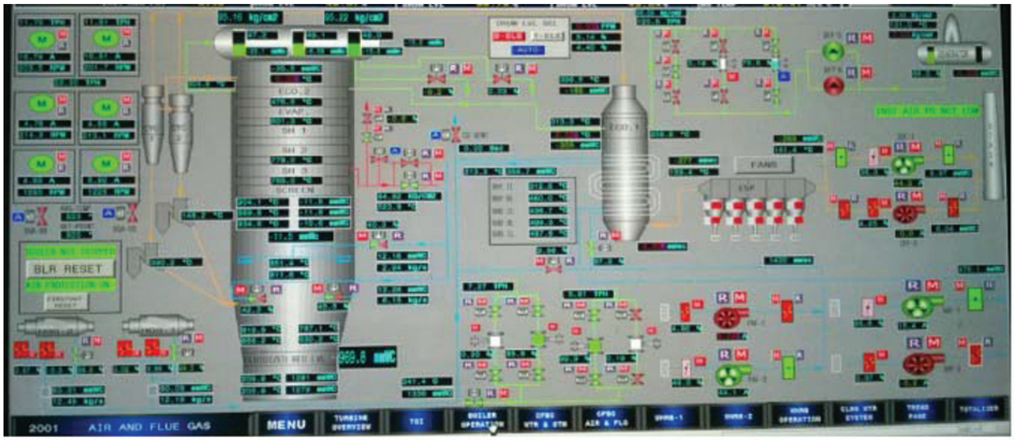

Fig.5: Air and flue gas passage 1

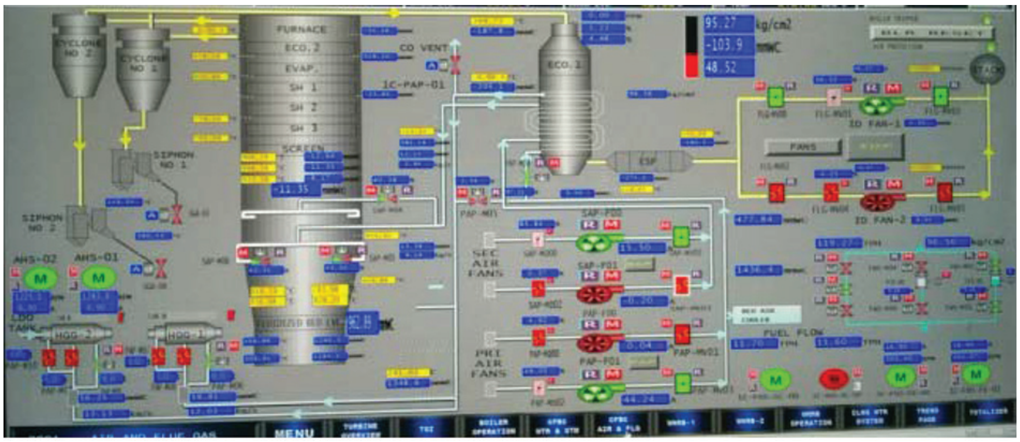

Fig.6: Air and flue gas passage 2

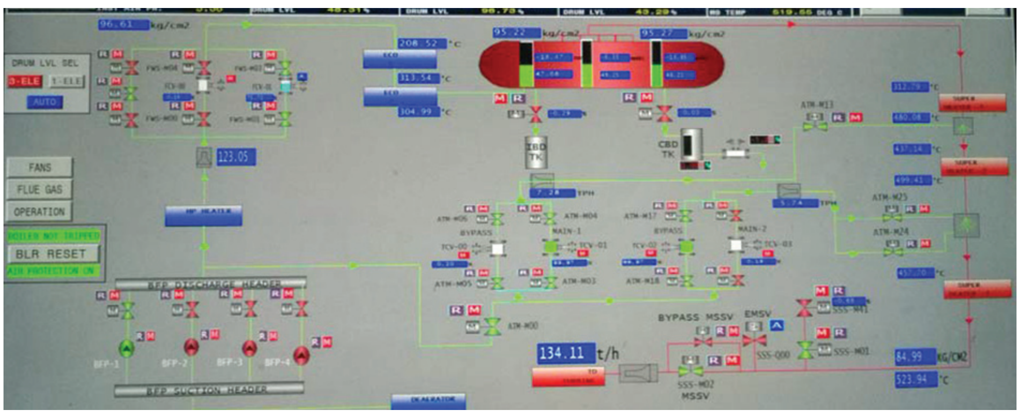

Fig.7: Water and steam circuit

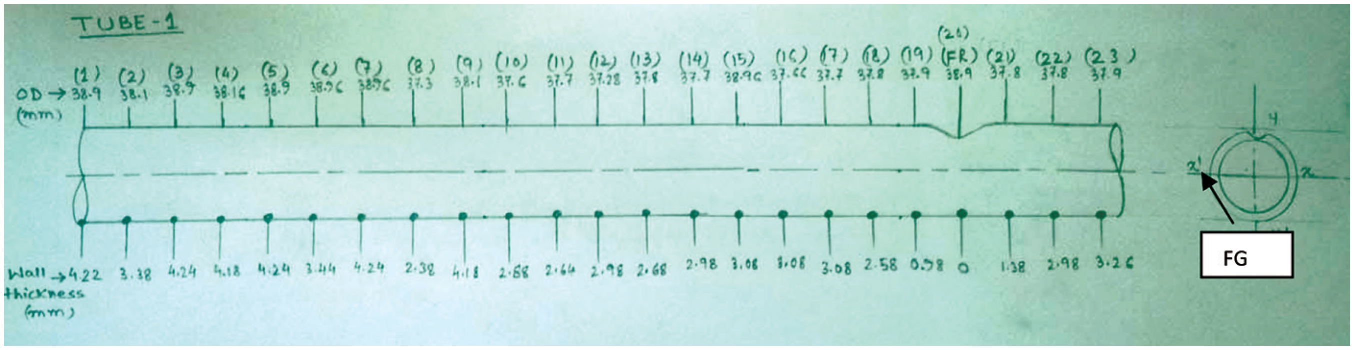

Fig.8: Measured readings of failed economiser tube 1

(FR) – Failure region; OD – Outer diameter •→ Wall thickness flue gas direction
OD corresponding to points 1, 2, 3, ... FR, ..., 23 in XX' and YY' directions.

TABLE 2

•	Distance from right (in mm)	Along XX^{l} (in mm)	Along YY^{l} (in mm)	Thickness (in mm)
1	230	38.9	38.94	4.22
2	220	38.1	38.1	3.38
3	210	38.9	38.96	4.24
4	200	38.16	38.9	4.18
5	190	38.9	38.96	4.24
6	180	38.96	38.16	3.44
7	170	38.96	38.96	4.24
8	160	37.3	37.1	2.38
9	150	38.1	38.9	4.18
10	140	37.6	37.6	2.88
11	130	37.7	37.36	2.64
12	120	37.28	37.7	2.98
13	110	37.8	37.4	2.68
14	100	37.7	37.7	2.98
15	90	38.96	37.8	3.08
16	80	37.66	37.8	3.08
17	70	37.7	37.8	3.08
18	60	37.8	37.3	2.58
19	50	37.9	35.7	0.98
20(FR)	40	38.9	34.72	0
21	30	37.8	36.1	1.38
22	20	37.8	37.7	2.98
23	10	37.9	37.98	3.26

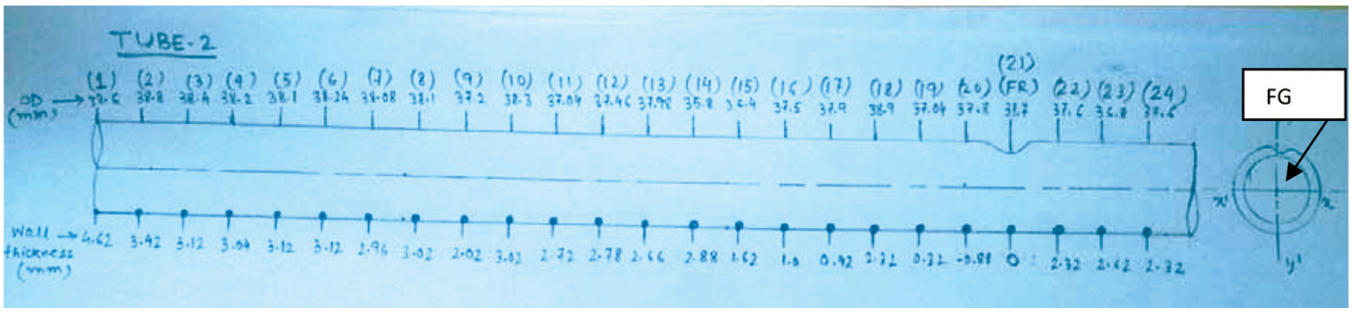

Fig.9: Measured readings of failed economiser tube 2

(FR) – Failure Region; OD – Outer diameter •→ Wall thickness flue gas direction
OD corresponding to points 1, 2, 3, ..., FR, ..., 24 in XX' and YY' directions

Table 3

	Distance from right (in mm)	Along XX[l] (in mm)	Along YY[l] (in mm)	Thickness (in mm)
1	250	38.6	39.7	4.62
2	240	38.8	38.5	3.42
3	230	38.4	38.2	3.12
4	220	38.2	38.14	3.04
5	210	38.1	38.2	3.12
6	200	38.24	38.2	3.12
7	190	38.08	38.04	2.96
8	180	38.1	38.1	3.02
9	170	37.2	37.1	2.02
10	160	38.3	38.1	3.02
11	150	37.04	37.8	2.72
12	140	37.46	37.86	2.78
13	130	37.98	37.74	2.66
14	120	35.8	37.96	2.88
15	110	36.4	36.7	1.62
16	100	37.5	36.08	1
17	90	37.9	35.5	0.42
18	80	38.9	37.4	2.32
19	70	37.04	35.4	0.32
20	60	37.8	34.2	-0.88
21(FR)	50	37.7	35.3	0
22	40	37.6	37.4	2.32
23	30	36.8	37.7	2.62
24	20	37.6	37.4	2.32

Table 4: Collected physical data from plant – temperature and pressure readings

Sr. No.	Description	Actual	Design	Unit
	Air and flue gas			
1	Furnace outlet temperature	392.65		DEG C
2	Furnace outlet pressure	-190	-180	mmWc
3	Flue gas pressure APH hopper	-212		mmWc
4	ESP inlet flue gas temperature	152.93		DEG C
5	ESP inlet flue gas pressure	-281.6		mmWc
6	ESP outlet temperature	141		DEG C
7	ESP outlet pressure	-295		mmWc
8	Flue gas pressure chimney inlet	6.5		mmWc
9	Flue gas temperature above screen	765.56		DEG C
10	Flue gas temperature above SH1	605.61		DEG C
11	Flue gas temperature above evaporator	480.78		DEG C
12	Furnace pressure above ECO-2	-40		mmWc
13	Furnace pressure above SH-2	-31.18		mmWc
14	ECO-1 inlet flue gas temperature	394.83		DEG C
	Steam and Water			
15	ECO-1 inlet temperature	220	230	DEG C
16	ECO-1 outlet temperature	312		DEG C
17	ECO-2 outlet temperature	305		DEG C
18	SH-1 inlet temperature	305		DEG C

(Continued on next page)

Sr. No.	Description	Actual	Design	Unit
19	SH-1 outlet temperature	475	400-450	DEG C
20	SH-2 inlet temperature	435	440	DEG C
21	SH-2 outlet temperature	500		DEG C
22	SH-3 inlet temperature	460	450-510	DEG C
23	SH-3 outlet temperature	525	540	DEG C
24	Drum pressure	96	105	Kg/cm^2
	Bed temperature			
25	Average	850	850-860	DEG C
26	Furnace temperature	850		DEG C
27	Furnace temperature	816		DEG C
28	Furnace temperature below screen	908		DEG C
29	Furnace temperature below screen	891		DEG C
30	Furnace temperature below screen	937		DEG C
31	PA discharge pressure	1417	1600	mmWc
32	PA pressure to hot gas generation	1313		mmWc
33	Wind box temperature	210		DEG C
34	Bed height	950	500-1400	Mm
35	PA air flow	24	15	Kg/s
36	SA discharge pressure	477	400-600	mmWc
37	SA pressure to furnace	360		mmWc
38	SA flow	6	7	Kg/s
39	TA flow	3	2.5	Kg/s
	Drag chain feeder			
40	Speed	200		RPM
41	Char feeder	220		RPM
42	O_2	4.4		%
43	O_2	5.2		%
44	Steam flow	135		TPH (tonne/hr)

4.0 Chemical analysis of corrosion deposits

Chemical analysis of the corrosion product inside failed tubes was carried out at different laboratories. The results of the chemical analysis of deposits is given in Table 5. Sample Description: Boiler tube scaling sample identification

4.1 Chemical analysis of tube materials

Metal samples from the two tubes were chemically analysed to estimate the weight percentage of the constituent elements.

Table 5: Test specification: boiler tube scaling: Test method: IS-13624/1993 (Reaffirmed 2003)

	Parameters (elements)	Unit	Result
1	Calcium (Ca)	%	9.39
2	Magnesium (Mg)	%	4.55
3	Sodium (Na)	%	0.30
4	Potassium (K)	%	0.18
5	Sulphur (S as SO_3)	%	22.47
6	Silica (SiO_2)	%	20.81
7	Bicarbonate	%	NIL

Table 6: Economiser tubes metal composition

Sample No.	Tube Identification	Composition (weight per cent)		
		C	Si	Mn
1 and 2	Economiser tube	0.20-0.19	0.15-0.16	0.48 – 0.49
Recommended grade: SA 210 A1	0.27 max	0.10 min	0.93 max	

5.0 Conclusions

The economiser tube failure prevention mechanism was established with following corrective actions:

(i) Arrangement to measure furnace flue gas outlet temperature: During inspection it was observed that, there was no provision to measure furnace exit gas temperature. There may be more secondary combustion in furnace top due to deviation in load-based tuning of secondary and tertiary air. The reduced heat transfer rate with rated heat transfer surface in economiser II tubing zone is causing excess flue gas temperature at economiser I inlet. Slag deposit on the outer surface of the tube, possibly due to faulty furnace exit draft set up or unavailable FEG temperature indication for standard operational practice, caused localized increase in metal stress leading to failure while erosion was caused by high velocity ash particles before entry to cyclone. The more fines in the freeboard zone with high velocity high ash coal particles are prime reason of erosion. Corrective measure: Tuning of secondary and tertiary air supply based on metal temperature and flue gas velocity mapping at furnace exit/cyclone entry may help in avoiding re-occurrence of similar failure in future. Long retractable soot-blowers may help in preventing fly ash deposits in economiser II tubes which are not installed now.

(ii) Arrangement to tube surface cleaning: The design/ performance and operational parameters of the economiser tubing at economiser I and economiser II indicated exposure to a temperature slightly above the designed temperature and this may cause in future of graphitization. Graphitisation is considered to be a serious type of microstructural degradation. Therefore, failed tube sample may be given for microstructural analysis to ensure trouble free operation in future. Corrective measure: Proper cleaning must be done to prevent the blockage of the tubes by depositing foreign materials. Moreover, flue gas temperature must be properly controlled to prevent localized increase in flue gas temperature. The sulphur content of the fuel fused slag accumulated at outer surface of failed tubes at the furnace top indicates inadequate combustion and inadequate proportion of sorbent recharge. As such, below 1mm coal particle size need to be controlled as per OEM recommendation. The sulphur content in slag may propagate tube external surface damage mechanism that may also tested to verify operational excursion that may be caused by acidic corrosion as a result of leaked steam at initial stage. Since free silica (SiO_2) concentration is significantly high with average ash content ranging to 65-70% of the Dolochar mix, the tube erosion potential is dependent on α-quartz concentration and its particle size distribution which may be tested too to determine service life of tubes.

(iii) Arrangement to shield fuel impinging tube surface: The arrangement of shielding of service exposed economiser tubes particularly towards the coal-ash impinging side with SA213 304H stainless tube halves of 2.5 mm thick and internal diameter of 38.1 mm (1.5 inch) may reduce the impingement linked erosion effect.

In oil and coal-fired boilers, soot build-up on tubes acts as an insulator against heat transfer. Any such deposits should be removed on a regular basis. An estimated 1% efficiency loss occurs with every 22°C increase in stack temperature. Therefore, stack temperature should be checked and recorded regularly as an indicator of soot deposits. It is also estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5% due to increased flue gas temperatures. Periodic off-line cleaning of tube surfaces within furnace, boiler tube banks, economisers and air heaters may be necessary to remove stubborn deposits. Reduction of boiler steam pressure is an effective means of reducing fuel consumption by as much as 1 to 2%. Lower steam pressure gives a lower saturated steam temperature and without stack heat recovery, a similar reduction in the temperature of the flue gas is obtained. Since the unit has not undergone a performance guarantee test to assess the performance, a boiler tuning test may be done to check the effectiveness of all set points of control parameters for available fired fuel and its composition.

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