

AN INSIGHT INTO INVESTIGATION OF REPETITIVE BOILER TUBE FAILURES

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ABSTRACT:

There was quick succession of failures of furnace water wall tubes in 16 years old Borsig make closed circuit Boilers in a short span of 6 months. Advance inspection techniques, maintenance practices were used to get the boilers on stream at the earliest possible time.

This paper presents details of the process of inspection, maintenance, operation and failure investigation carried out for the failures of the furnace water wall tubes of the boilers.

The failure of the furnace wall tubes of Boiler was due to internal corrosion of the tubes facing furnace fire side due to presence of chlorides, high levels of dissolved oxygen and copper ingress.

KEY WORDS:

Borsig Boiler, Furnace Water wall Tubes, Low Frequency Electromagnetic Technique, STG Condenser, Boiler Feed Water.

INTRODUCTION:

The objectives of today for any power plants are to increase the availability, efficiency and reliability of power generating systems. Boilers are considered heart of steam and power generation systems. Unpredictable failures in boilers can bring down operation of power and steam generation to a halt for many days based on the severity of failure / damage.

Proper operation and maintenance of boilers can ensure prolonged and safe operations of the power / steam generation systems. However, during downtime of these equipment, inspection and repair at the fastest possible time play a major role in bringing back the power and generation systems. Inspection and repair time are very crucial as the failure down time of boilers directly affect other dependent plants in terms of supply of electric power and utility steam.

In this paper an attempt is being made to present failure analysis of boiler, corrective methods followed and inspection and repair execution to bring the boilers back to operation at the shortest possible time.

BRIEF DESCRIPTION OF BOILER SYSTEM:

There are three Borsig make close circuit Boilers at Reliance Industries Limited, Patalganga, commissioned in 1987.

These boilers are natural circulation three- pass radiant type developed for generating high-pressure steam of 100 BarG at 495 Deg.C at the rate of 70 T / Hr each.

The Borsig boiler is of fully welded construction having membrane walls. The furnace wall and sidewalls of the second pass consist of evaporator tubes having a outside diameter of 57mm with 18mm steel fins welded between wall tubes. The rear wall of the second pass is designed as down comer wall consisting of tubes with outer diameter of 101.6mm. The tubes are directly connected to the steam drum. This system permits unrestricted circulation to all water walls and is standard design of Babcock – Borsig one-drum radiation type boilers.

The boiler is of self-supporting type. This design allows free expansion of pressure parts in all directions.

The main parts of the boiler are:

- a. Furnace and radiation chamber,
- b. Flue gas pass for convection type heating surfaces,

This arrangement avoids flame radiation from furnace into super heater sections. Refer Figure 1 for schematic of the boiler.

BRIEF DESCRIPTION OF FAILURE:

The boiler had tripped on high furnace pressure caused due to water leak from the riser furnace water wall tube. On opening the boiler furnace chamber, the chamber was found filled with water. Furnace water wall 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. The location of the rupture / pin holes is as shown in the layout of the furnace chamber (refer Figure 2).

Only the Side wall tubes of the furnace chamber were found leaking. No external corrosion / oxidation or bulging of tubes was observed.

INSPECTION OBSERVATIONS:

Different inspection techniques were employed for inspection of the boiler with special emphasis on the Furnace chamber tubes with an objective of reliable inspection technique at the fastest possible rate of inspection. Major and significant observations of important inspection techniques used are briefly given below.

Visual Inspection of leaking furnace water wall tubes:

Refer Figure 2 for the layout of furnace chamber showing locations of leaky tubes.

The leaky tubes, in the mid section of side furnace wall were found with typical ruptured hole of about 1.5” diameter. The ruptured hole was found to be of irregular shape. Refer Figure 3.

The hole was located at about 10 feet above the Furnace chamber floor level. The hole was found to be in match line of bottom side of muffle block of top burner.

Internal inspection of the tube was carried out using fibroscope through the ruptured hole. Internal surface of the tube exactly opposite the rupture hole was found covered with a black layer of magnetite. Grooving and roughness on internal surface of the tube was observed above and below the ruptured hole along the axis of the tube. Circumferentially no grooving or surface roughness observed inside the tube around the ruptured hole.

External surface of the tubes with ruptured hole was found free of corrosion or pitting. No evident bulging observed in the tubes.

Hardness testing of tubes:

Hardness testing of the furnace wall tubes on OD was carried out by portable ultrasonic hardness meter. The hardness of the tubes was found in the range of 190 to 210 BHN, which is considered to be satisfactory hardness.

In-Situ Metallography of tubes:

In-Situ metallography of select tubes of side wall and burner wall tubes was carried out on outside surface of tubes facing furnace chamber. The locations of checking in-situ metallography were at the areas where reduction in thickness was noticed in the tubes as well as near these areas with thickness in normal range of nominal thickness.

No major abnormality in the microstructure of the tubes observed. No carbide formation, grain boundary separation or elongation of grains observed. The microstructure was found to be identical with 15Mo3 metallurgy.

Ultrasonic Thickness survey of Furnace water wall tubes:

In regular outages (annual shutdowns) of boilers, ultrasonic thickness gauging of the Furnace water wall tubes is carried out. The locations of the thickness measured are fixed and thickness of the tubes is carried out at the same spots and reduction in tube wall thickness is checked with respect to the nominal thickness values and last measured thickness values.

However, after the failure of the boiler tubes, ultrasonic thickness gauging carried out at conventional select locations could not be considered reliable and extending the scope of this testing was more time consuming. Hence an alternative inspection testing was required to be explored which could pinpoint internal localized corrosion of the tubes.

Inspection of tubes using Low Frequency Electromagnetic Technique (LFET):

For fast, reliable, and accurately finding hard to find highly localized defects / corrosion in the furnace water wall tubes, an advanced technique called Low Frequency Electromagnetic Technique (LFET) was employed. It is a multichannel NDT system for scanning boiler tubes from O.D. It detects and quantifies ID, OD and internal material defects in ferrous and nonferrous materials. The system uses a dry non-contact method base on the principles of Electromagnetics. It is forgiving to uniform surface scales and tests at a scanning speed of 10

to 15 ft. (3 to 4.5 m) per minute. The data is real time display of high resolution colour graphics with 3D display.

The OD of the furnace water wall tubes facing the furnace chamber (fire side) were checked by LFET using probes suitable for the OD of the tubes. The areas of the tubes found with abnormality as indicated by phase change were marked and re-examined by ultrasonic flaw detection. Refer Figure 4 for LFET inspection and a typical waveform display of corroded tube.

About 9 side wall tubes of the furnace chamber were found with reduction in thickness on ID due to internal corrosion. The location of these abnormalities was found to be in the burner zone (about 150mm to 1800mm above the floor level of furnace chamber).

No abnormality was observed in burner wall and front wall tubes of the furnace chamber.

Internal inspection observations of failed tubes:

Tubes with thickness in the range of 1.7mm to 2.2mm were cut out. Length of the tubes to be cut out was based on extent of reduction in thickness indicated by LFET and ultrasonic thickness survey.

These removed tubes were sliced opened longitudinally along the filling piece axis for internal inspection of the tubes.

At the locations where reduction in thickness was observed, internally the tubes were found corroded with burnt corrosion product around the thinned down locations. Refer Figure 5.

The corroded locations were observed only in the section of the tubes facing the furnace chamber. No pitting or corrosion observed on the internal surface of tubes away from furnace chamber (rear side of the tubes)

Internal surface of the tubes facing the furnace chamber were also found with reddish coloration and localized bubbling / nucleating marks were also observed.

The internal surface of cut out tubes facing away from the furnace chamber (rear side) was found uniformly covered with dull black magnetite scales. No bubbling or nucleating marks observed in these sections of the tubes.

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 1.

The corrosion product was found with predominant water soluble chlorides (190 wt. ppm), Copper (0.72 to 1.63%) and phosphates and iron oxide.

SPECTROSCOPY OF DEPOSITS:-

EDXA (Energy Dispersive X-ray Analysis): The result indicated presence of copper, chlorides, phosphate and iron as major constituents.

ESCA (Electron Spectroscopy for Chemical Analysis) and SEM (Scanning Electron Microscopy): ESCA and SEM was carried out for the corroded portions of the ruptured furnace water wall tubes. The scales were found to be predominantly iron containing some amounts of Copper and Chlorides. The corrosion scale was found to be thicker than normal protective magnetic oxide scale and it was found to be more porous.

METALLURGICAL ANALYSIS OF FAILED TUBES:-

Chemical analysis of the failed tubes carried out separately at different laboratories. The chemical composition of the failed tubes conformed to 15Mo3 material of construction as per specification of the furnace water wall tubes.

Microstructure across the thickness of the ruptured tube indicates ferrite – pearlite structure without any grain growth or grain boundary separation. The amount of pearlite in the inner edge (water side), outer edge (fire side) and centre of the tube sample was found to be uniform. There were no signs of decarburization in the microstructure. Refer Figure 6.

DISCUSSION ON CAUSES FOR INTERNAL CORROSION OF TUBES:

Lack of Preservation of boilers and inadequate precautions during startup of idle boilers:

The boilers had been in idle conditions for varying periods ranging from 5 to 15 days with the steam drum filled with water and vent valve of the drum kept open. During this time there are chances of oxygen getting diffused into the boiler water and making it corrosive.

The boiler system needs to be preserved properly to prevent any ingress of oxygen.

It has been noticed that idle boilers were fired with water already hold up in system which may be saturated with oxygen due to lack of preservation. This would aggravate corrosion at vulnerable areas within pits already formed or in places where scales are formed or copper is deposited.

Inefficient Deaeration:

The Dissolved Oxygen (DO) levels in the Deaerators were found higher than desired values before the boiler failures. The DO was found to be in range of 80 to 100ppb against specified value of less than 10 ppb.

Copper ingress in Boiler Feed Water:

Copper and chlorides were observed in the deposits of failed tubes. The condensate system mapping was carried out to identify the source of copper. Steam Turbine Generator condenser (tubes made of Copper alloy: CuZn 28 Sn) outlet condensate sample was analysed and copper in the condensate was found to be about 37ppb.

Inspection of the STG condenser was carried out using Eddy current testing. 2 tubes were found with 40 to 80% wall thickness reduction.

This indicates shell side corrosion of the copper tubes of the STG condenser.

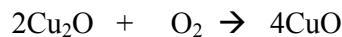
Findings of copper in condensate system confirmed that the copper leach out from STG condenser is finding its way in to the boiler feed water.

Presence of copper in boiler is detrimental and cause corrosion as per following mechanism:-

Corrosion of copper by oxygen generally results in formation of cupric oxide, and the reaction is self limiting.

With presence of ammonia, the copper oxide film cannot become stable. The oxidation of the base metal takes place and is washed away. Copper release is caused due to high local pH of condensate system in combination with ammonia solution.

In the presence of dissolved oxygen, ammonia is capable of forming highly soluble copper ammonium salts $[\text{Cu}(\text{NH}_3)_2]^+$, that are swept away with the condensate. While ammonia itself is not corrosive to copper alloys, it dissolves copper oxide coating as per following reaction-



Further, ammonia reacts with copper oxide as follows:-



The copper condenser tubes can get leached out by presence of carbon dioxide getting into the condenser through leaks, improper blanketing of DM water, etc.

The leached out copper travels to boiler through condensate makeup.

Accelerated Internal corrosion of tubes due to presence of contaminants or deposits and galvanic corrosion due to ingress of copper in boiler feed water treatment system:

From the deposit analysis it is observed that the predominant elements were phosphates, chlorides and copper.

The phosphate deposits might have been adherent to the internal tube surface since the time when the boilers were on coordinated TSP-Hydrazine water treatment programme.

Higher heat flux at the randomly distributed deposits in the water wall tubes might have caused localized increase in the concentration of chlorides in the water and pitting of the tubes. Higher concentrations of chlorides might have removed the protective magnetite scales on the tubes.

Once the protective magnetite scales are removed, the steel tube can corrode and the rate of corrosion gets accelerated if noble elements like copper are present in an environment of electrolytic / ionic condition of water. The plated out copper on the tube surface acts as a galvanic couple with the steel tube.

The filming amine corrosion inhibitors are known to be intolerant for contaminants like chlorides.

Presence of the chlorides was traced out to some batches of filming amine chemicals supplied in cans, however these cans were analysed only after failure of the boiler. Before failure of the tubes, it is possible that the concentration of chlorides might have been much higher.

CONCLUSION:

The failure of Furnace water wall tubes is attributed to waterside tube internal corrosion caused by improper preservation of boilers, inadequate removal of dissolved oxygen, presence of contaminants like chlorides and copper and inability of water treatment to inhibit the corrosion.

A strict Quality Control and Assurance is required to be followed for boiler feed water treatment chemicals. Proper operation of the boilers with respect to monitoring and control of process parameters like dissolved oxygen, contaminants like copper or chlorides, proper preservation of idle boilers and periodic chemical cleaning of the boilers are essential elements which can prevent failures. Exploration and use of advanced inspection / NDT techniques, employing automated maintenance tools drastically reduce downtime of boilers and improve availability and reliability of the steam and power generation systems.

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REFERENCES:

1. Public Works Technical Bulletin 420-49-21, "Boiler Water Treatment – Lessons Learned", Nov. 1999.
2. R. K. Dayal and N. Parvathavarthini, "Hydrogen embrittlement in power plant steels", pp 431-451, Sadhana, Vol. 28, Aug. 2003.
3. Glenn N. Showers, PE, "The importance of Burner Management Control", pp 39-41, HPAC, Dec. 1997.
4. S. Tuurna, O. Cronwall, L. Heikinheimo, M. Hanninen, H. Talja, O. Tiihonen, "State of Art Report – Lifetime Analysis of Boiler Tubes", VTT Technical Research, Oct. 2003.
5. M. N. Hovinga, G. J. Nakoneczny, "Standard Recommendations for Pressure Part Inspection during a Boiler Life Extension Programme", International Conference on Life Management and Life Extension of Power Plant, May 2000.
6. Darryl Rosario, Peter Riccardella and Thomas Sherlock, "A Risk Management Approach for Boiler Waterwall Tube Failure", EPRI Maintenance Conference, June 1999.
7. W. M. M. Huijbregts, J. H. N. Jelgersma and A. Snel, "Influence of Heat Transport, deposits and Condenser leakages upon Corrosion in Steam Generators", pp 26 – 39, VGB Draftwerkstechnik, Jan 1975.

Table 1: Results of Chemical Analysis of Corrosion Product Deposits from failed Tubes.

Tests	Laboratory #1 Results	Laboratory#2 Results
Appearance	Blackish hard deposit, magnetic in nature	
Volatiles at 650 Deg.C	<0.1%	
Ash Content at 650 Deg.C	99.9%	
Iron as Fe ₂ O ₃	99.2 %	95.49%
Chromium as Cr	0.25 %	0.11%
Copper	0.72 %	1.63 %
Phosphate	209 ppm	1.92 %
Sulphate	<5 ppm	0.38%
Water soluble Chlorides	190 ppm	0.01%
Acid insolubles	<0.01 %	

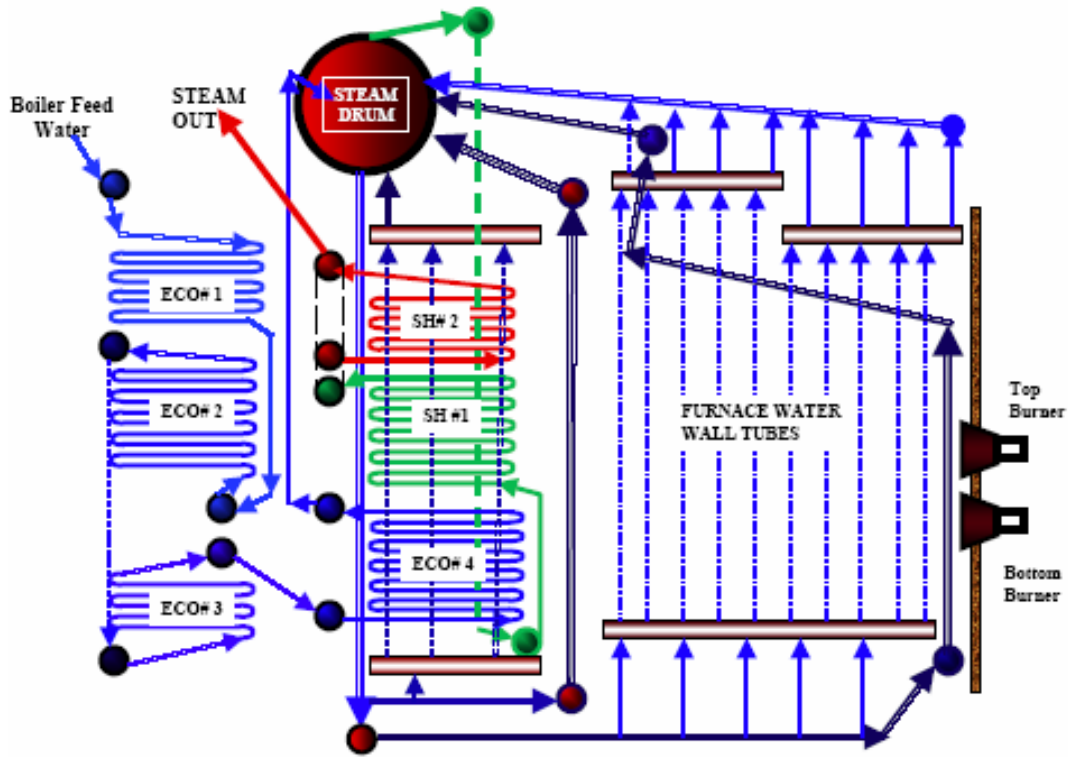


Figure 1: Schematic showing construction of Borsig Boiler.

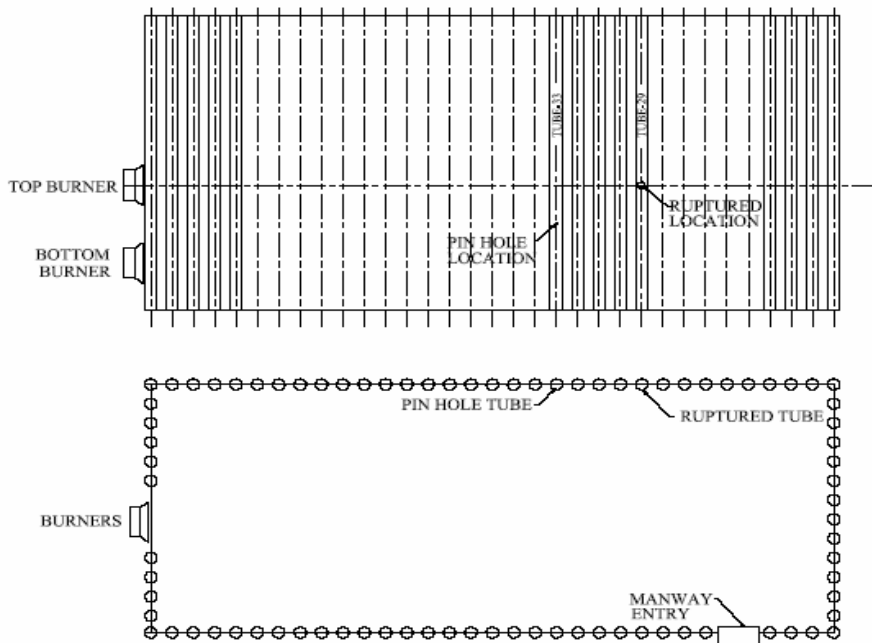


Figure 2: Furnace Chamber Layout showing location of failed tubes of side wall.

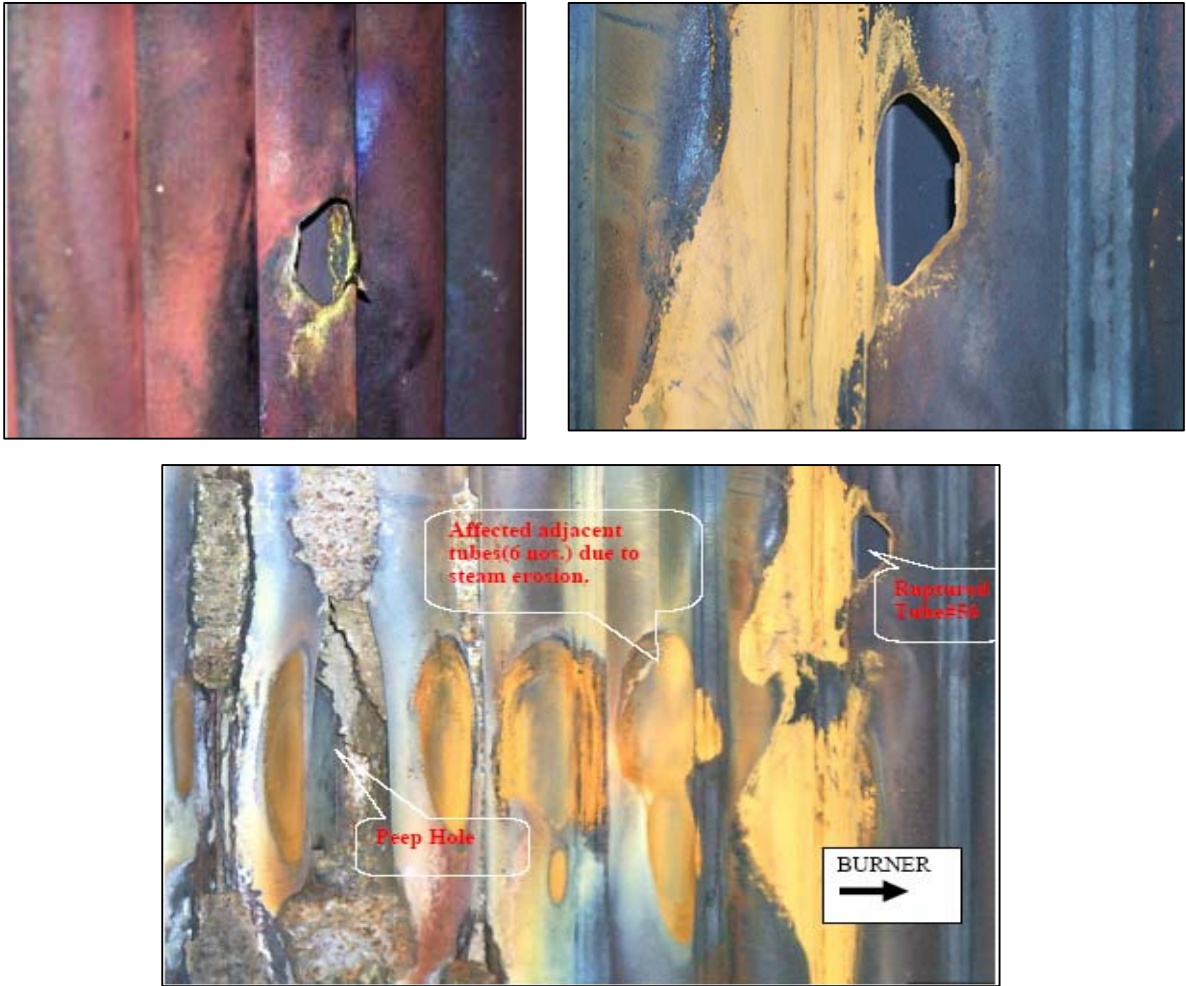


Figure 3: Photographs of ruptured Furnace water wall tubes.

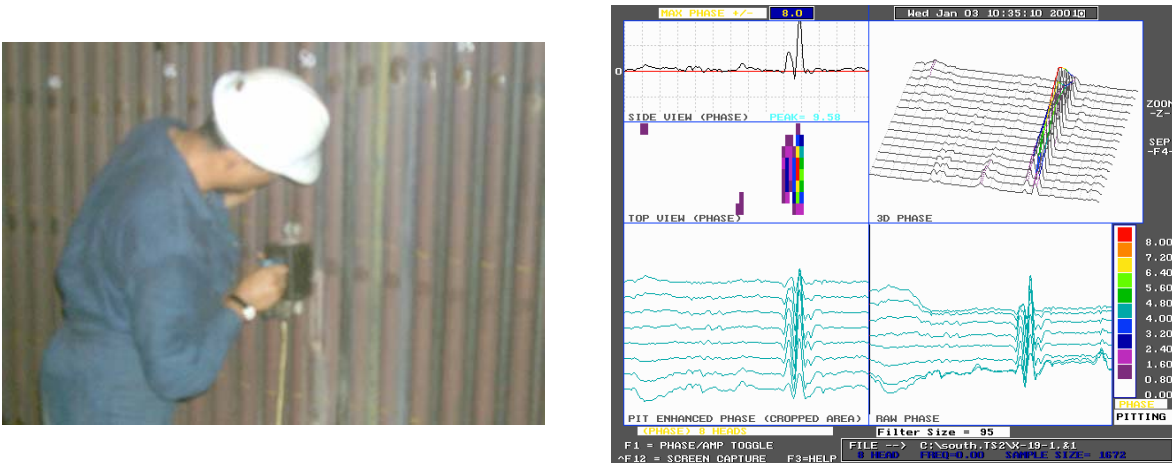


Figure 4: LFET testing of Furnace Water wall tubes and typical waveform display of LFET at internally corroded tube.

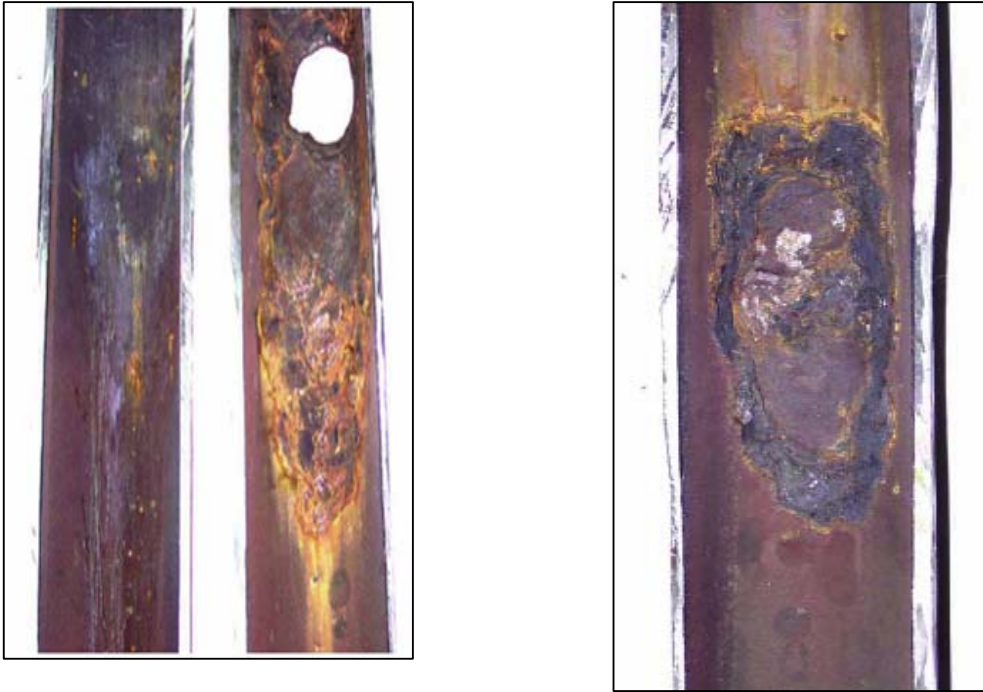


Figure 5: Internal corrosion and deposition of corrosion product inside the Furnace waterwall tubes.



Fig.15a



Fig.15b

Figure 6: Microstructure across the thickness of tube showing uniform distribution of ferrite – perlite structure.