Failure Analysis in High Pressure Feed Water Heaters and Method to Find the Defect in Tubes

M. Ramesh and S. Manavalan

Abstract--- *The aim of this study is to analyze the causes of tube failure of the high pressure feed water heaters in thermal power plants and to find out the defective tubes in high pressure feed water heaters using simple and economical method. A feed water heater is used to preheat the boiler feed water in thermal power plant. Most of the feed water heater used in thermal power plant is shell and tube type. In this type of feed water heater, water flowing inside the tube and steam condensing in outside of the tube i.e., shell side. The source of heat used in high pressure feed water heater is steam bleed from the turbine. The high pressure feed water heaters are used to improve the thermodynamic efficiency of the cycle and also reduce the coal consumption of the thermal power plant. Sample of the failure tube were taken to analyze the causes of tube failure in high pressure feed water heater by visual inspection, using tube thickness measurement analysis, Examining Mechanical properties and chemical composition of the tube material and methodologies for finding the tube failure in advance to prevent the breakdown of high pressure feed water heaters. Based on the above analyses, it is observed that the high pressure feed water heater tubes failure occurred due to tube outer diameter erosion.*

Keywords--- *High Pressure Feed Water Heaters, Tube Failure, Corrosion, Erosion.*

I. INTRODUCTION

In thermal power plants, high pressure heaters are used to heat the feed water using bleed or extraction steam. A portion of steam extracted from turbine is called as bleed steam or extraction steam. This steam is used in high pressure heaters to heat the feed water. Latent heat of this bleed steam is utilized in feed water heaters, otherwise it will lost in condenser with cooling water. Using this heat energy, over all cycle efficiency of the plant is increased.

In thermal power plants, High Pressure (H.P) feed water heaters are connected in feed water line between Boiler feed pump and economizer. There are two types of feed water heaters are used in thermal power plant.

1. Open feed water heaters
2. Closed feed water heaters

Mostly closed type feed water heaters are used in thermal power plants to heat the feed water and also open type feed water heater is used for feed water de-aeration purpose. The open heater in such a system is called de-aerator.

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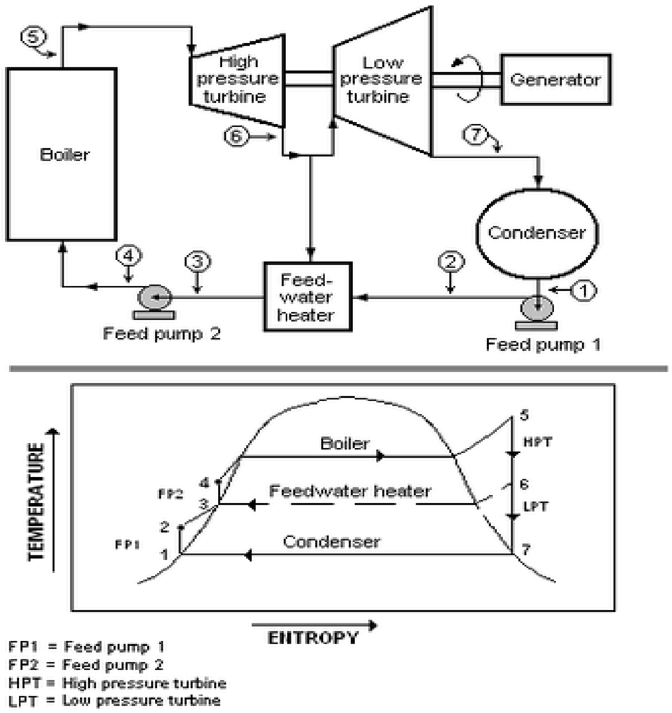

Fig.1: Feed water heater cycle

In closed feed water heater, water flows through the tubes in the heater and bleed steam condenses on the outside of the tubes in the shell. The closed feed water heater has three zones.

1. De-Superheating Zone

The incoming steam enters this zone, giving up most of its superheat to the feed water exiting from the heater.

2. Sub Cooling Zone

The condensed steam enters this zone at the saturation temperature and is cooled by convective heat transfer from the incoming feed water.

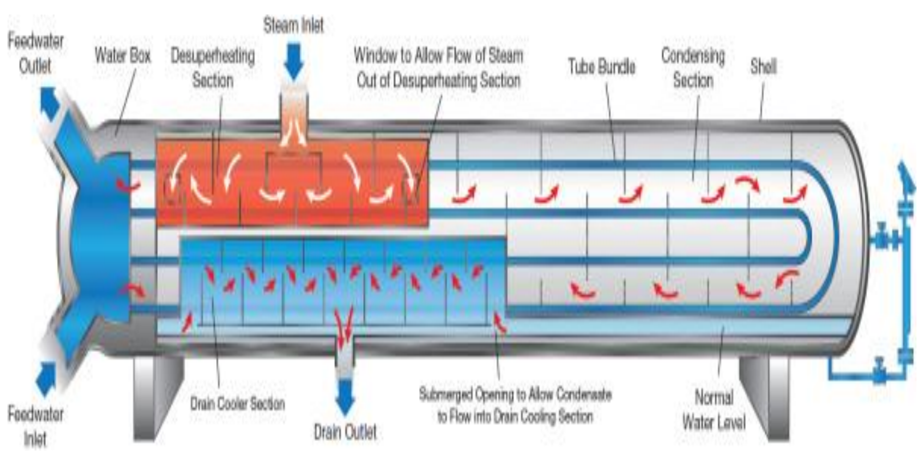

Fig.2: Different zones of Heater

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3. Condensing Zone

All feed waters have this zone. All of the steam is condensed in this area, and any remaining non condensable gases must be removed. A large percentage of the energy added by the heater occurs here.

The closed Feed water heaters can be located either horizontally or vertically.

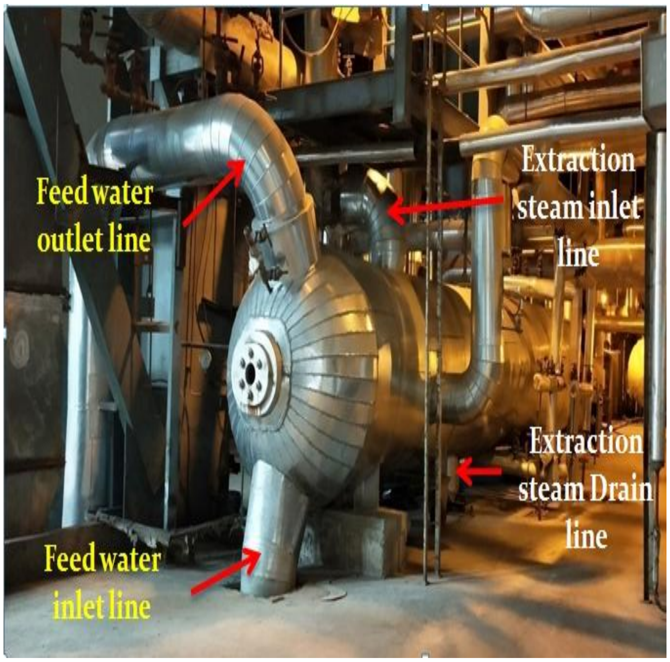

Fig.3: High pressure feed water heater

Temperature Profiles

The temperature profiles for a high-pressure feed water heater which receives superheated steam extracted from a high-pressure turbine.

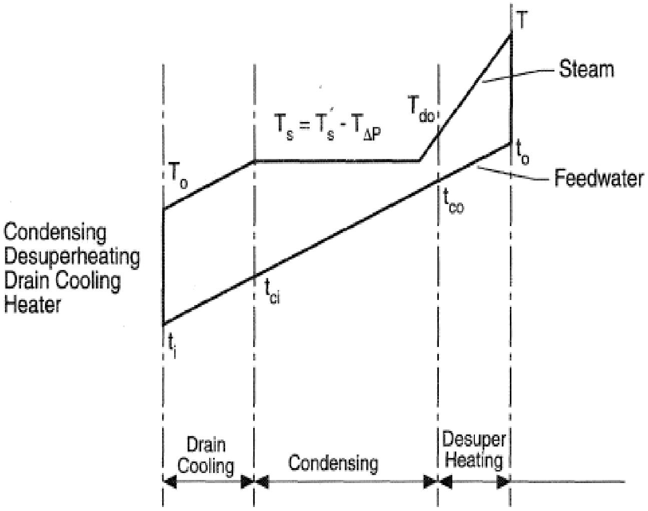

Fig.4. Temperature graph

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II. TUBE FAILURE MECHANISM

In general, High Pressure feed water heaters are fails due to one of the following reasons.

A. General Corrosion

General corrosion is the most common form of corrosion [3]. It occurs by a chemical or electrochemical reaction that proceeds uniformly over the entire surface. Due to this chemical reaction, thickness of the tube becomes progressively thinner and eventually fails because of the stress loadings imposed on it.

B. Crevice Corrosion And Pitting

Crevice corrosion is a localized corrosion of a metal surface[1]. It may occur, due to porous scales, corrosion products, mud or debris, attached to the tube surfaces. When the creviced areas are small, the resulting localized corrosion may resemble pitting attack.

Chloride plays a critical role in pitting and crevice corrosion. The chloride value in feed water must to be maintained below less than 1.2 ppm, if the value of chloride increases above the mentioned level the tubes will have localized corrosion. The stress level includes residual stresses and service stresses. Residual stress may occur during a manufacturing process or installation. Service stress is caused by an expansion stress, hoop stress, or bending stress. For stainless steel materials, this includes the presence of concentrated chlorides [4, 5]. Chlorides enter in to the Feed Water system when there are condenser tube failures.

C. Galvanic Corrosion

Galvanic corrosion of a metal that occurs because of an electrical contact with more noble metal in a corrosive solution.

The less resistance metal is called as anodic and the more resistance metal described as cathodic [3].

D. Erosion - Corrosion

Erosion-corrosion is a form of localized corrosion [1]. It is also called as water side impingement attack. It occurs on the water side of the tubes due to mechanical disruption of the protective oxide film. In areas, where the turbulence intensity at the metal surface is high enough to create mechanical disruption.

E. Stress Corrosion Cracking

Stress corrosion cracking (SCC) that occurs when a susceptible alloy is stressed in tension in a particular corrosive environment [3]. At least one environment condition, all alloys are susceptible to Stress corrosion cracking. The growth of stress corrosion cracking is slow. In High Pressure feed water heaters, SCC failures are initiated mostly on the steam side of the tube. In water side, limited numbers of Stress Corrosion Cracking failures only was observed.

III. METHODOLOGY AND ANALYSIS OF TUBE FAILURE

The following test methods and analysis have been performed to investigate the failure of high pressure feed water heater tubes.

A. Eddy Current Test

Eddy Current Testing (ECT) is a nondestructive test technique based on inducing electrical currents in the material being inspected and observing the interaction between those currents and the material.

Eddy currents are generated by electromagnetic coils in the test probe, and monitored simultaneously by measuring the probe's electrical impedance.

Eddy Current Test were carried out in defective high pressure feed water heater to find the defective tubes using probes. During this test, thicknesses of the tubes were measured and weaker tubes were identified. Most of the tubes affected in De – Superheating zone area was noticed during this Eddy Current Test.

Fig.5: Eddy current test

Advantages

- High speed inspection with a bobbin coil
- Detects pits, cracks, wear, wall thinning and more
- Repeatable examination
- Reliable data

Disadvantages

- It is difficult to find out the circumferential cracks with conventional bobbin Exam
- Cost of the eddy current test is high.
- Highly qualified technicians required to conduct the test.

B. Air Leak Test

To find out the probable causes of failure of the tube, it is essential that the exact location of each failure must be known. Before conducting air leak test in high pressure feed water heaters, tube and shell side water must be drained.

In this method air is used as working medium. Initially 0.2 kg /cm2 air is to be applied on the shell side. The face of the tube sheet is covered with soap water to detect any air flowing from the open ends of a tube with a failure. If found air leak, seal off both ends of each tube using rubber stoppers. If no tube leaks are noticed, slowly increase the air pressure to a maximum of 7.0 kg/cm2. Using the Probe to locate the tube leak. Insert the probe into the leaking tube. This will seal off air flow the insertion end of the tube until the probe has been inserted far enough to reach the point of failure.

As soon as the probe crosses the area of tube failure, air will blow out of the plastic tube is to be immersed in water. An increased flow of bubbles in the water indicates that a leak has been located. If the failure is very small, air will stop blowing through the other end of the feed water heater tube when the failure has been passed by the probe seal.

If the failure is long split, air will continue to blow out of both ends until the probe has been advanced across the other end of the failure. The probe is to be moved back and forth slowly to identify both ends of the failure. The length of the failure is equal to the distance moved minus 50 mm. Once a failure has been located the depth of the leak into the bundle is to be determined by measuring the length of probe inserted into the failed tube. Where tubes have failed directly behind the tube sheet, particularly attention should be given to the tube to tube sheet joint.

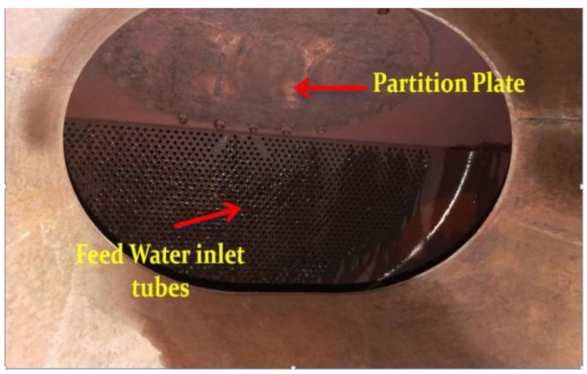

Fig.6: View of water tubes in heater

Fig.7: Soap water test

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Fig.8: Inspection of Water tubes

Fig.9: Identified punctured tubes

Fig.10: Plugging of tubes

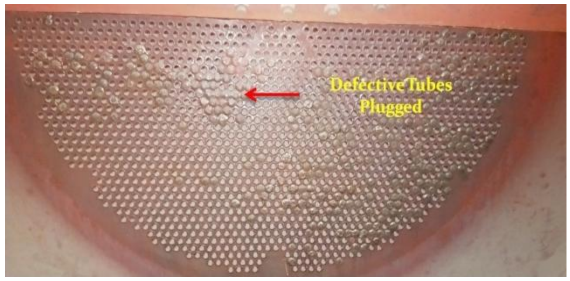

Fig.11: Rectified Feed water tubes

Advantages

1. It is easy method to find out the circumference failure of the tube
2. The cost of test comparatively lesser than the Eddy Current Test
3. Highly qualified technicians not required to conduct the test

C. Visual Examination

In some types of corrosion, visual examination can suggest the cause of failure and mechanism of attack. A photograph is usually recorded for subsequent reference and comparison of defects. Corrosion pitting of steel may be present in variety forms, it caused by dissolved oxygen in the working fluid. The pitting is commonly in the form of shallow oval pits overlaid with brown.

Fig.12: Feed water Heater Tube Bundles

Fig.13: Sample Tubes

Fig.14: Tube Measurement

Fig.15: Degraded tube portion

D. Water Analysis

In thermal power plant, feed water treatment is most important and requires careful water analysis. Chloride plays a critical role in pitting and crevice corrosion. It is better to maintain the chloride value in feed water is “null”. If the value of chloride increases above the mentioned level the tubes will have localized corrosion. A laboratory evaluation for the tube specimen from failing locations, water analysis to check if there is any deviation from the standard conditions.

Table 1: Feed water analysis

		Conductivity µs/Cm	*PH Value*	*Chloride ppm*	*Sio_2 ppb*	*NH_3 ppm*	*N_2H_4 ppm*	*DO ppb*
Feed Water	Max	6.7	9.1	0.003	Nil	0.62	0.02	12
	Min	6.1	8.6	Nil	Nil	0.60	0.02	7
	Limits	5 to 7	8.8 to 9.3	NT	< 20	< 1.0	≤ 0.02	< 10

E. Chemical Analysis

Chemical analysis for tube samples taken from the defective high pressure feed water heater is very important to identify the percentage of changes in material alloys compared with original percentage [3]. It leads to assess the reason of the damaged condition.

For example, the carbon content has a great effect on the mechanical properties of the carbon and low alloy steel tube material. Where any changes in carbon percentage will lead to a general reduction in the mechanical properties of the tube material. Other reduction in the tube alloys like chrome content has an effect on the corrosion resistance of the tube material.

F. Mechanical Analysis

In high-temperature and high-pressure power plant, Mechanical properties are the principle guide to the selection of materials for construction of the plant [3].

If any change in design mechanical properties of the material of the heater, tube will affect the construction capabilities against circumference condition. For example, the surface hardness is an indication of the material ability to resist wear.

If any reduction of surface hardness property, it will lead to reduction in the wear resistance of the tube material against liquids containing suspended solids which likely to causing erosion.

G. Macroscopic Scanning

Dissolved iron is a good indicator of corrosivty of the feed water of the thermal power plant. It happens when an increase in the dissolved oxygen, carbon dioxide, and ammonia are present in the feed water of the power plant.

Dissolved oxygen, which becomes very active as the water temperature increases, will unit with the atomic hydrogen, forming H2O and producing the necessary cathodic reaction for progressive corrosion [3]. Oxygen corrosion occurs typically as small pits and depressions.

Hydrogen ion concentration in water indicates the acidity or alkalinity of the water. The hydrogen ion concentration is expressed as the pH value.

pH value of more than 7 indicates alkalinity, while less than 7 indicate acidity. pH value determines the intensity of corrosion [3].

IV. RESULTS OF TEST AND VARIOUS ANALYSIS

Two types of experimental and various analysis are discussed. The first experimental employed to the inside damages of the heater tubes and second experimental employed to the outside damages of the heater tubes and also find out the defective location of the tube. Various analyses employed to the feed water passing through tube side sampling and the steam passing through the shell sampling.

From the results of Eddy current Test, Air leak test, visual inspection and laboratory investigation concerning the defective heater tubes, the following notes have been obtained:

A. Eddy Current Test

From the Eddy current test, thicknesses of the heater tubes are measured and percentages of eroded tube thickness were noticed. Also weaker tubes are identified and plugged.

B. Air Leak Test

From the air leak test, it was noticed outer diameter of the tube side defects in feed water heater and also exact location of the failure occurs in the tubes were measured. Also Tube to Tube sheets defects are identified.

C. Visual Inspection

From the visual inspection of the defective feed water heater tubes, most of the defects are found in the tubes in de-superheating zone and these tubes are severely affected in outer side of the tubes due to erosion and pitting problem.

D. Water Analysis

The water analysis results show deviation in the pH values, dissolved oxygen, chloride values from the recommended limits. Chloride plays a critical role in pitting and crevice corrosion. High value of the chloride is observed in feed water. The chloride value in feed water is 0.003 ppm while the recommended value is '0' ppm. This high value of chloride in feed water creates localized corrosion in feed water heater tubes.

High value of dissolved oxygen content is observed in feed water. The oxygen content in feed water range is 7 to12ppb, while the recommended value is less than 10 ppb.

A depression in pH value of feed water under the recommended value is also noticed, where the pH value ranges between 8.6 to 9.1 ppm for the feed water, while its recommended value in the range of 8.8-9.1 ppm. The test results are shown Table 1. The deviations in both pH value and dissolved oxygen are the most effective reasons of the corrosivity of the power plant feed water.

E. Chemical Analysis

The results of chemical composition analysis in defective high pressure feed water heater tubes indicated that, the alloy material of tube show significant reduction in the alloy additive percentage as compared with that of the new tube.

V. CONCLUSION

1. From the above study of various types of high pressure feed water heater tube failure mechanism, it was found that OD (outside diameter) erosion is the major type of failure mechanism. It leads to tube failure in high pressure feed water heater of thermal power plant. The location of the most susceptible to OD wear is in desuperheating zone at the entrance of extraction steam. Even with the presence of the impingement baffle above the tube bundle these type of failure occurs. From the visual examination it is noticed that, the highest affected region is near edge of the baffle.
2. The depression in the carbon content and carbon segregation, which is Randomly distributed throughout the microstructure of the used tube, is the two main causes of the depression in the mechanical strength of the tube material, which accelerates the OD erosion mechanism.
3. Deviation of chemical content from the feed water specifications from recommended value of the power station especially chloride, dissolved oxygen and pH value has resulted in high corrosion and premature failure of the tubes. On installation of the Condensate Polishing Unit (CPU) the unavoidable oozing of chemicals in the condenser was eliminated.

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Fig.16: Mixed bed Condensate polishing Unit

Table 2: Feed water analysis with CPU

		Conductivity μs/Cm	PH Value	Chloride ppm	Sio2 ppb	NH3 ppm	N2H4 ppm	DO ppb
Feed Water	Max	6.7	9.1	Nil	Nil	0.62	0.01	7
	Min	6.1	8.8	Nil	Nil	0.60	0.01	5
	Limits	5 to 7	8.8 to 9.3	NT	< 20	< 1.0	≤ 0.02	< 10

1. The macroscopic scanning for the tube samples shows that carbon Segregation is randomly distributed through the microstructure as compared with the new tube samples scanning. This in turn leads to moderate loss in mechanical strength of the material. This result from prolonged overheating at a temperature above the permissible operating temperature for the tube alloy material. This process is highly accelerated when the heaters are used as a by-pass for the steam pass through the shell side, while no water routed through the tube side.

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VI. RECOMMENDATIONS

1. Provide isolation valve before the extraction valve for the steam in the shell side to avoid overheating of tubes resulted from steam passing the shell with the absence of feed water flowing through tubes.

2. Provide an-ion and cat-ion mixed bed condensate polishing unit (CPU) for removal of oozing chloride and removal of excess hydrogen ion concentration in condensate water (Table.2). The oozing chloride enter in to the condensate water is possible at condenser. This chloride creates localized corrosion in feed water heater tubes. Where using mixed bed condensate polishing unit, cat ion act as H+ and Anion act as OH. When condensate water enter into the CPU, all the chlorides are removed from water by cat -ion resins and these resins become as HCL and excess hydrogen ion concentrations are removed from water by an-ion resins and these resins become as H2O.

3. Tubes in the feed water heater should be periodically inspected to determine their conditions. For a regular inspection, the plan should include tubes in the de-superheating zone, tubes in drain cooler section, tubes around previously plugged tubes and some tubes at random. In addition to regular inspections, inspection after a tube failure is highly recommended.

4. Leaking tubes should be immediately plugged. Such action leads to effective plugging and avoids future outages.

5. Regular checking and calibration of the instruments used in feed water analysis are necessary to avoid any deviation of water specification from recommended values.

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