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Case Study on Premature Failure of Super-Heater Tubes in Oil & Gas Fired Boiler

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1. ABSTRACT

Captive power plant (CPP) is a necessity of any refinery to provide uninterrupted supply of key utilities like steam & power. The CPP makes use of oil & gas fired boilers that produce steam by utilizing feedstock fuels to minimize fuel & loss of the refineries. As a consequence the boiler operators faces challenges to ensure reliable boiler operation by burning different blends of fuel oil(FO) & fuel gas(FG) with varying composition & calorific value. In this process both the radiation & convection zone tubes of the boiler are subjected to anomalous heat loads whenever there is a variation in the composition / calorific values of the FO & FG which is being used as fuel. This paper discusses a condition which led to the long term overheating & subsequent failure of pendant type super-heater tubes of a 150TPH capacity boiler. Critical design parameters, maintenance constraints and operating conditions of the boiler are highlighted that caused the failure of the super-heater tubes of MOC SS-347 & T-22. Metallographic analysis of the tubes and relevant chemical analysis of the deposits are discussed to determine the cause of failure along with measures taken to prolong the life of the boiler.

Keywords: Keywords: Boiler, Super-heater, Creep, Oxidation, Long term Overheating

2. INTRODUCTION

In the process of crude oil refining, refineries produce Fuel Oil (FO) along with substantial amount of off gas consisting mainly C1 and C2 which is used as Fuel Gas (FG). The calorific value of FG varies significantly because of continuous change in composition of off gas. Thus both FO & FG are used as fuel for oil and gas fired boilers burners to produce an uninterrupted supply of steam. The boiler in discussion has a 150 tonnes per hour capacity which was installed to produce superheated steam by utilizing the feedstock FO & FG as its fuel. Within 3 years of its service the boiler was brought out of operation due to leakage in the pendant type platen superheater coils. Based on visual observations, fractography & metallographic examination the failure was attributed to long term overheating. Various operating conditions & parameters, maintenance constraints & design limits are discussed in the paper that contributed to overheating. Measures taken to prolong the life of Boiler are also mentioned.

3. BRIEF DESCRIPTION OF THE BOILER

The bi-drum, natural circulation boiler has a pressurized furnace made up of fin-welded water walls. Relevant operating parameters of the Boiler are mentioned in Table 1 & 2.

Table 1. Design Data of Boiler

Capacity(Tons/Hour)	150
Superheater Steam Outlet Pressure(kg/cm^2)	41
Superheater Steam Outlet Temperature (^oC)	440

Table 2. Flue Gas Temperature (^oC)

Primary Superheater Inlet	1132
Secondary Superheater Inlet	1002
Boiler Bank Inlet	821

Saturated steam from steam drum is superheated in two stages. The first stage of heating is carried out in hanging platen superheater coils (Primary Superheater) followed by final stage heating in secondary superheater coils (Final Superheater). 42 no. of platen superheater coils lie in the radiation zone of the boiler and are arranged in 14 rows as depicted in Fig. 1. The coils are laid vertically and separated by a steam cooled spacer tube. Material of construction of Primary Superheater is SA 213 T22 & SA 213 TP347H as shown in Figure 2. The temperature of outlet steam is controlled using a spray type attemperator located between Primary & Secondary Superheaters

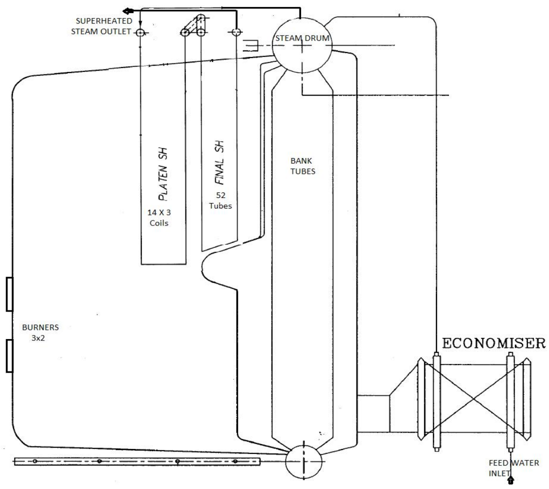

Figure 1. Schematic View of the Boiler.

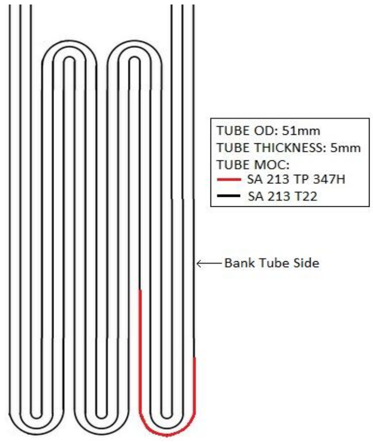

Figure 2. Schematic View of the Platen Superheater.

4. FAILURE REPORTING

Three years after continued service the boiler was brought out of operation due to suspected leakage Subsequently hydro test of the boiler was carried out and leak from 9 number of platen super-heater bends were observed. Comprehensive inspection of the tubes was carried out and swelling around the bends was also observed in 6 other tubes. In total 15 tubes were replaced with MOC SA213 P22.

Along with the superheater coils failure was also experienced in the times in steam cooled spacer tube used to maintain space between the Platen Superheater.

Figure 3. Arrangement of hanging platen Superheater Coils as seen from bottom of tubes. Location of failure was concentrated in first 7 tube clusters(counting from left) in the 3rd row (MOC SA 213 TP 347H), which was away from the burner.

Note: Failure was also observed in the steam cooled spacer tube. (Horizontal tube in the figure)

5. VISUAL OBSERVATIONS

All the failures in the Platen Superheater tubes were from the bottom U bend locations. As evident from Fig. 1, the bends are subjected to both radiation heat from the burner flame and convection heat from the flue gas. Following are the major observations based on visual inspection:

5.1 Thick and hard clinker deposits were observed on the external tube surface of both T22 & TP347 H tubes. Narrow openings in the tubes were observed when the deposits were forcefully removed from the swollen part of the tubes as shown in Figure 4, 5 & 6.

5.2 Severe localized swelling was observed in the coils near the U bends in all the 15 affected tubes. Other than localized swelling no appreciable OD growth was observed in the tubes.

5.3 Multiple cracks aligned parallel to the longitudinal direction of the tubes were observed. Narrow openings with thick lip, indicative of long term overheating, were also observed in the tubes.

5.4 Thick & adherent oxide scale formation was observed on the internal & external surface of T22 tubes. Upon dissecting the tubes thickening of magnetite layer was observed in the internal tube surface. Cracking of the internal & external oxide layer was observed in the bulged location of the tubes.

5.5 Out of 15 failed bends, 8 were of MOC TP347 H. Majority of failed T22 bends were also adjacent to the TP 347 H bends. Therefore the failure was experienced in the bends facing the bank tubes. No failure or swelling was observed in the bends directly facing the burner

Figure. 4

Figure. 5

Figure. 6

Heavy clinker deposits can be seen in the tubes. Localized swelling and narrow openings with thick lips can also be seen in the images.

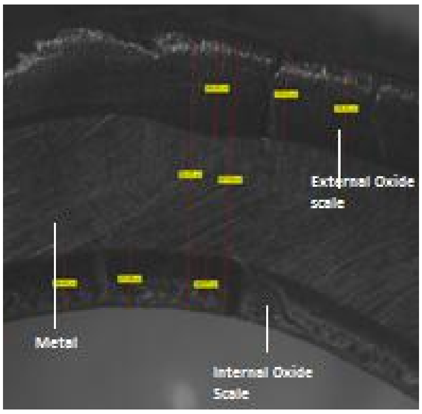

Figure. 6
Stereograph along the thickness of tubes showing thick oxide scales

Figure. 7
Oxide scales on the external surface of the tube. Cracks in the layer can be seen in the bulged portion of the tube

Figure. 8
Oxide scales on the internal surface of the tube.

6. MATERIAL IDENTIFICATION

The material of failed tubes was verified using X-Ray spectroscopy. The tubes were found conferring to the original material of construction i.e. SA213 TP347 H & SA213 T22. Detailed chemical composition of the tubes is given in Table 3.

Table 3: Chemical Composition of Tubes

Chemical Composition(%)	Cr	Mo	Mn	Ni	Fe	Nb
SA213 T22 (1.25 Cr – 0.5 Mo)	2.25	1.08	0.5	0.87	95.20	Nil
SA213 TP347H (SS347H)	17.36	0.22	1.73	9.64	70.55	0.50

7. METALLOGRAPHY

Tube samples of both TP347 H & T22 were collected and microstructural analysis was carried out. Metallurgical degradation resulting from overheating can be seen in the microstructures.. Polished tube samples were electrochemically etched and viewed under optical microscope at 200 X magnification. Following are the major observations:

7.1 Microstructure of the T22 samples, as shown in Figure 9a, 9b & 9c, consist of deformed polygonal grains forming the ferrite matrix. Unlike the undamaged tube location, the microstructure of bulged location has globular carbide precipitation inside the grains and on the grain boundaries. Creep voids along the grain boundaries were also seen in the microstructure.

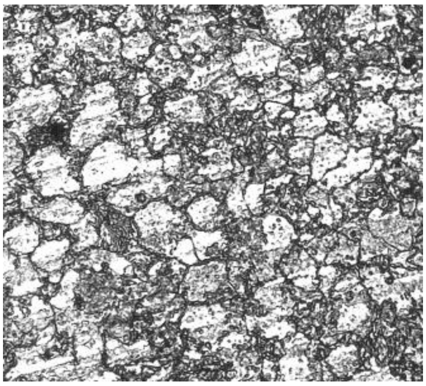

Figure 9a.

Microstructure of SA 213 T22 Tube away from the rupture location at 200X.

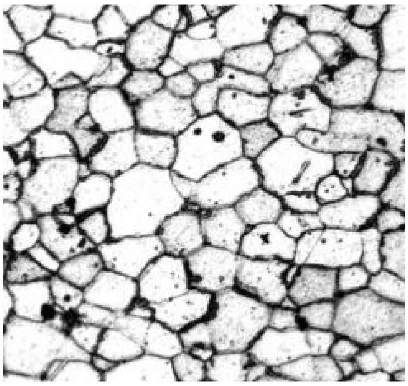

Figure 9b.

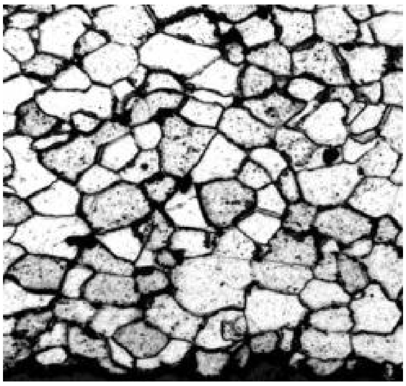

Figure 9c.

Microstructure of SA 213 T22 Tube at the rupture location at 200X. Unlike Fig 8a, globular carbide precipitation and microvoids can be seen in the matrix & grain boundaries

7.2 Microstructure of TP347 H tubes, as shown in Figure 10a, 10b & 10c, shows austenite grains with heavy carbide precipitation on the grain boundaries, marking the sensitization of the stainless steel material. Moreover creep voids at grain boundaries suggesting creep damage can also be seen.

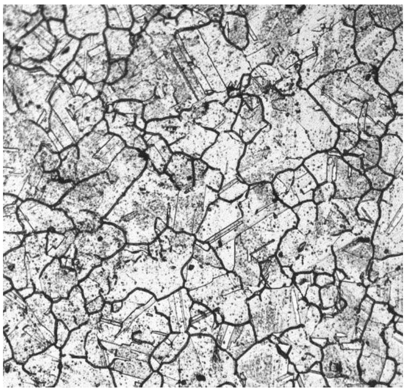

Figure 10a.

Microstructure of SA 213 TP347H Tube away from the rupture location at 200X.

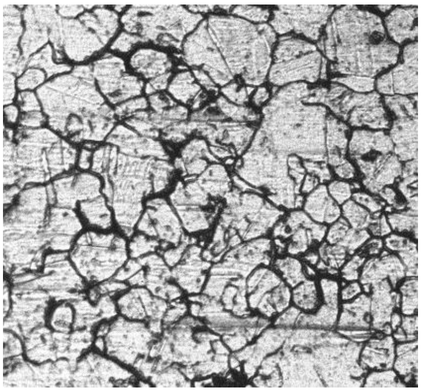

Figure 10b.

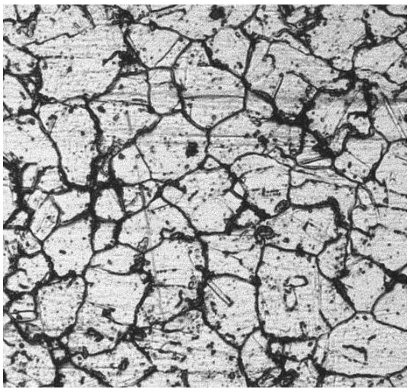

Figure 10c.

Microstructure of SA 213 TP347H Tube at the rupture location at 200X. Carbide precipitation along grain boundaries indicating sensitization can be seen in the microstructures.

8. CAUSES OF FAILURE

Based on visual examination and microstructural analysis the cause of failure of the Superheater is long term overheating which was furher aggravated by severe oxidation of the tubes. It can therefore be concluded that the failed Platen Superheater bends, already present in hottest zone of the boiler, was subjected to high heat fluxes leading to increase in the tube wall temperature above the design limit. Following conditions were identified as contributing factors towards the failure.

8.1 OPERATING CONDITIONS

8.1.1 Intermittent Flame Impingement

To optimize operational efficiancy, the fuel gas (FG) used as fuel in the boiler is derived from the process off gases which is the by-product of crude refining. Since a refinery consists of multiple process units, the FG composition changes significantly with changing process parameters or unit interruptions.

As a result, intermittent flame impingement was observed on the Superheater coils through the peepholes present in the furnace. During post failure inspection soot deposition, at the same elevation as that of Superheater bends, can be seen on side water wall panels suggesting in-service flame impingement. Moreover at various times the calorific value of the FG was found more than the designed value aggravating the overheating effect of the flame on the tubes. This is substantiated by the fact that of the total 15 Superheater tubes failure occurred in the zone affected by flame impingement.

8.1.2 Soot Deposition

Thick & adherent ash deposition was observed on superheater coils because of simultaneous FO firing in the boiler along with FG. Because of these deposits and presence of thick oxide scales, having poor thermal conductivity, different parts of the superheater coils were subjected to different heat loads. This anomalous temperature distribution led to localized overheating of the coils.

8.2 MAINTENANCE CONSTRAINTS

8.2.1 Locking of Air Dampers

The movement of air dampers in the burner assembly was restricted when the boiler was in operation. Because of this during exigencies the air flow to the burner could not be controlled as per the requirements. This led to the uncontrolled and irregular flame length of the burners contributing to flame impingement. Despite in-service maintenance free movement of the dampers could not be ensured to control the air flow inside the Boiler.

8.2.2 Malfunctioning of Soot Blower

The Soot Blower present near the Platen Superheater malfunctioned during the operation because of which ash deposits could not be removed from the tubes. This contributed to localized overheating of tubes as described in section 8.1.2.

8. PREVENTIVE ACTIONS

Comprehensive maintenance of the boiler was carried out for rectification of leakage and to prevent further occurrence of such failure. Following measures were taken to prolong the life of the Boiler.

8.1 Overhauling of air dampers was carried out to ensure smooth air flow control inside the boiler to control the flame length

8.2 Maintenance of soot blowers was carried out followed by regular soot blowing of the Superheater.

8.3 External cleaning of tubes were carried out using grit blasting to remove all external deposits from the tubes.

8.4 Ceramic ropes were tied on the bends of Superheater coils in the high heat flux zone to maintain the tube skin temperature below design limit.

9. CONCLUSIONS

The primary reason for premature failure of Platen Superheater Tubes was concluded as overheating which led to severe oxidation and creep. Operation & Maintenance constraints leading to failure were identified and resolved to increase operation reliability & mechanical integrity of the boiler.

10. ACKNOWLEDGMENTS

We would like to acknowledge the support of our senior colleagues for their sharing their experience and imparting their knowledge to identify & rectify the causes of failure of the boiler.

11. REFERENCES

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