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FAILURE ANALYSIS AND RECTIFICATION OF FISH MOUTH LIKE RUPTURE IN SUPERHEATER TUBE

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Abstract*- The present study is related to the superheater tube failure of Boiler-1 which is under operation at Karnafhuli Fertilizer Company Limited (KAFCO). Superheater is a crucial component of any boiler, and its failure leads to the shutdown of the entire plant. We investigated a fish mouth shaped rupture on the SA213-T11 secondary superheater coil that failed after running 78,840 hours. The reason for the fish mouth like rupture is short term overheating may be due to a restriction of steam flow for blockage inside tube although later no tube blockage observed by boroscopy inspection. Boroscopy was carried out in both headers if the tube is totally/partially plugged to prevent a second failure, and a videoscopic inspection was performed to find scale formation inside the tube. In the rectification process, the mellographic test was done to understand failed tube condition and identify the appropriate repair solution for short-term operation. Although the hardness tests of failed tube near the positions of welding ensured the suitability of replacement at reduced operating pressure, the existing material SA213 T11 of the Secondary coil was recommended to be changed with SA213 T22 as well which is the current material of primary SH tube coil at the plant mentioned above.*

Keywords: Superheater coils, Fish-mouth-shaped rupture, Boroscopy, SA213 T11, and SA213 T22

1. INTRODUCTION

KAFCO has two natural circulation natural gas fired package boilers of MACCHI, Italy. The boiler furnaces operate under positive pressure and in completely water cooled condition of furnace floors, walls and roofs consisting of membrane wall construction. The furnace is completely enclosed by water walls. The space between the tubes is closed by the fins, which overlaps each other thereby forming a completely gas tight seal enclosure. The water walls are rear wall, intermediate wall and front wall. There are D-tubes forming the floor, side and roof walls. These tubes are continuous construction entering directly into the steam and water drums. Suitable excess door are provided on the front wall, intermediate wall and side wall in order to inspect furnace, superheater and boiler bank tubes during boiler overhaul. Supplies for steam production are water, natural gas, and air. Design capacity of each boiler is 95 ton/hour at 100%, but Maximum Continuous Rating Production is 85 ton/hr. While Feed water temperature is supplied at135^{0}C, product steam pressure and temperature are 112kg/cm^2 and 510^{0}C respectively.

On December 07, 2015 at 23:22 Hrs. utility operation noticed that Boiler-1 load is suddenly going down and HP steam header pressure was falling. To cope up the steam demand, Boiler-2 load increases up to 118% while boiler-1 load goes down up to 55%. Primary super heater outlet temperature was also falling while secondary super heater outlet temperature was increasing rapidly. Due to such abnormal behavior utility operation perform shut down of Boiler-1 at around 00:05 Hrs. It was assumed that boiler tube was ruptured and severe noise was heard from inside the Boiler-1.

2. BRIEF DESCRIPTION OF THE BOILER

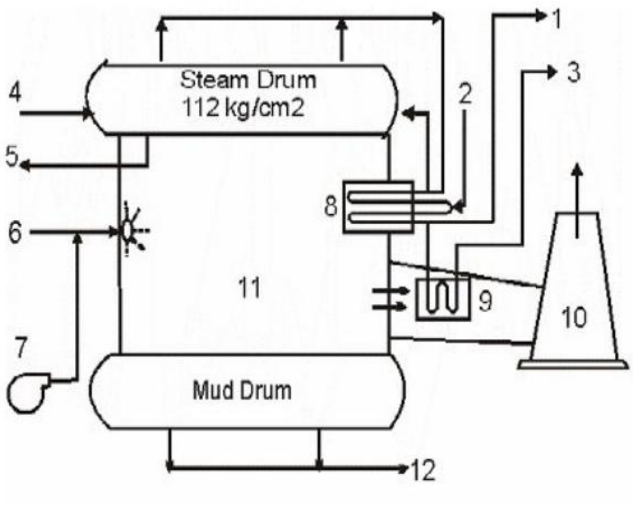


Fig.1: Boiler and its input output

Table 1: Description of boiler and its input output

Number	Name	Description
1	Boiler production	High pressure (HP) steam to header, 85 ton/hour at 510^{0}C
2	Desuperheater	BFW added to maintain HP steam temperature at 510^{0}C
3	Boiler feed water	BFW, 87ton/hr to steam drum at 140^{0}C gaining temperature through economizer up to 190^{0}C
4	Chemical dodging	Phosphate solution to create passive layer inside steam drum
5	Continuous blow down	Keep impurities such as silica concentration constant in the loop
6	Natural Gas	At a rate of 6.5 KNm^3/hour as source of heat energy
7	Forced Draft fan	Supply combustion air at 80 T/hr. Motor and steam
8	Superheater	Increase saturated steam temperature from 323^{0}C to 510^{0}C

3. BRIEF DESCRIPTION OF THE MATERIALS

SA213 T11 and SA213 T22 materials are currently in use for primary and secondary super heater respectively. SA213 T22 is higher grade steel, because it utilizes more amounts of Chromium and Molybdenum making it more corrosion resistance at high temperature. The incident of superheater coil failure hints the management of KAFCO to opt for the SA 213 T22 material for using in future.

Table 2: Chemical Composition (%) for SA213 T11 and SA213 T22 Low Alloy Steel

Chemical Composition	SA213 T11	SA213 T22
UNS Designation	K11597	K21590
Carbon	0.05—0.15	0.05—0.15
Manganese	0.30—0.60	0.30—0.60
Phosphorus	0.025	0.025
Sulfur	0.025	0.025
Silicon	0.05—1.00	0.50
Chromium	1.00—1.50	1.90—2.60
Molybdenum	0.44—0.65	0.87—1.13

Table 3: Mechanical properties for SA213 T11 and SA213 T22 Low Alloy Steel

Mechanical Properties	SA213 T11	SA213 T22
Tensile Strength	415MPa	415MPa
Yield Strength	220Mpa	220Mpa
Elongation	30%	30%

4. SUPERHEATER TUBE FAILURE INSPECTION

After shutting down the boiler, it took around 14 hours to cool down the boiler for internal inspection. Preliminary visual inspection revealed that, first tube of Secondary Superheater inlet (SH2 I^0) (Tube No. 62) was ruptured and fish mouth appearance at ruptured spot was observed. Due to sudden rupture of tube no. 62, the outer leg of the tube heats the inner leg. Due to high pressure and temperature steam hydrojetting, adjacent tube No 61, 63, 64, 65 was found magenetite formation at tube outer surface and blackish scale was formed at the steam contact points. Fish mouth opening was estimated roughly 100 mm and at the edges of the mouth cracks are observed. The rupture tube was found bulged and bended due to the reaction force of leakage. The leaked tube bowed at inner direction around 16 inches.

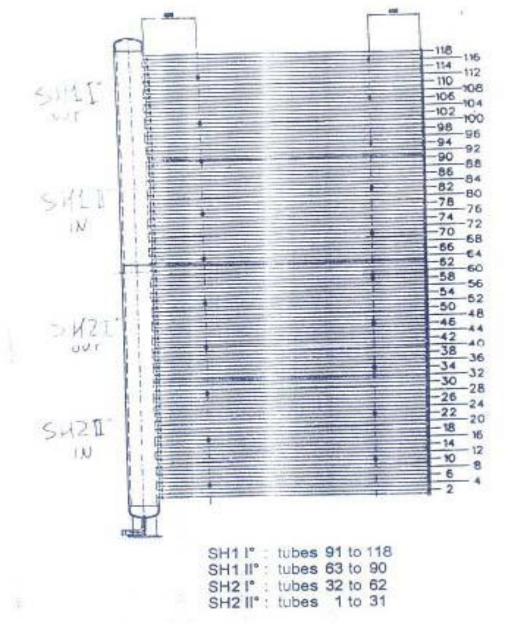


Fig.2: Schematics of the superheater tube assembly

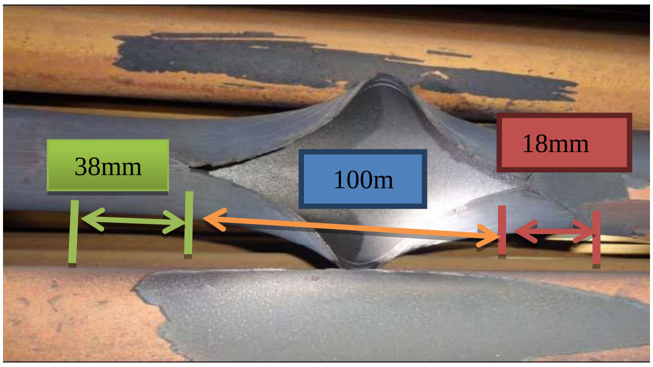


Fig.3: Measurement of fracture surface

4.1 Reason for the Failure

Reason for the fish mouth like rupture is short term overheating. A blockage inside tube might hinder the steam flow; however, no tube blockage could be detected while performing boroscopy inspection. Therefore, the reason of the failure could be attributed to the condition of increasing of fire-side convective coefficient and temperature, or decreasing of steam-side convective coefficient that leads to the curbed mass flow of steam, thereby causing a significant increase of the tube metal temperature. Such an increase in the temperature of the tube under high operating steam pressure results in creep rupture of the coil.

4.2 Consequences in Other Area

Situation was critical for KAFCO because

1. Urea plant was shutdown
2. Ammonia plant would reach alarming condition to sustain production after due to limitation of storage tank capacity
3. In case of unavailability of both boilers, total plant could pose to a total uncertainty. In such case, even Ammonia plant would not have been able to go into operation.
4. Unavailability of any unscheduled ship in the market for selling liquid ammonia.

5. RESTORATION ACTION

On confirmation of the extent of damage, all out efforts were taken in various directions with immediate effect.

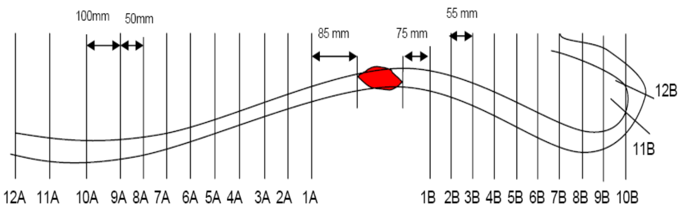
1. Maintenane schedule for six days restoration works based on 13 hours job
2. Explore skilled work force experieced in this field at home and abroad
3. Deployment of a dedicated work force comprising KAFCO and hired man power
4. Mobilize own resourece without any delay to cater the schedule
5. Explore in house spare parts
6. Communicate to MACCHI(boiler manufacturer) for repairing procedure

The boiler manufacturer was contacted for the suggestions to proceed with repair works. MACCHI responded and suggested:

1. Measure thickness of failed tube so as to compare with good one
2. Hardness test of failed tube near the positions of welding to ensure the suitability of repair
3. Carry out boroscopy in both headers if the tube is totally/partially plugged to prevent a second failure
4. Restore the super heater by installing a by-pass. Window welding is suggested to weld from inside where welding access is not possible from outside.
5. Collect sample and carry out mellographic tests to understands the tube condition

The idea of plugging the damage tube was not considered due to bad after effect of plugging and as this plugging was not possible to carry out at header joint due to access limitation.

In the light of MACCHI recommendations, inspection personnel measured the parameters of failed tubes of secondary SH coil which are tabulated here.



Measurement Segment	Measured Thickness, mm Nominal: 6.3 mm	Measured Hardness, HB TA-15: 127HB (Tube 58)	OD, mm Nominal: 51.0
1A	4.13	90	52.0
2A	4.82	103	53.0
3A	4.84	90	53.0
4A	5.80	97	53.0
5A	5.33	102	53.0
6A	5.43	95	52.0
7A	5.50	95	51.0
8A	5.77	96	52.0
9A	5.20	98	52.0
10A	5.90	110	51.6
11A	6.00	100	51.6
12A	5.90	100	51.0
1B	5.70	129	52.0
2B	6.10	139	51.0
3B	5.70	107	51.0
4B	5.90	115	52.0
5B	5.90	111	51.5
6B	5.90	103	51.7
7B	6.30	109	51.2
8B	6.40	108	51.5
9B	6.40	118	51.5
10B	6.40	110	51.0
11B	6.00	107	51.0
12B	5.64	135	50.0

Fig.4: Thickness, hardness and diameter measurement data of damage tube

6. REPARING OF BADLY DAMAGED TUBE NO. 62

As per MACCHI's short time repair procedure, it was decided to replace the ruptured portion with the section of spare tube available with us. As shown in the above figure, it has been observed that significant change of diameter and thickness value occurred in the right side of the rupture, minor change of hardness value observed along the tube length. Sound tube portion can be utilized for welding by removing at least 300 mm from both edge of the cracked portion. However, we cut off the length of 1380 mm and connected a sort piece from a spare tube coil.

6.1 Repair Process

Existing coil tube cutting & end preparation activities:

1. Cut off damaged portion by length as long as the condition was found good. It was 1380 mm.
2. Straighten the tube end by heating (using gas burner) at bend position
3. Both end preparation

Short Piece preparation and welding activities:

1. Cut a short piece of desired length from spare coil (Material SA 335 –T22).
2. Window cutting for inside welding form new short piece.
3. Outside and inside beveling to match with existing tube end.
4. Insert new short piece with maintaining root gap 2 to 3.2mm.
5. Root pass welding with GTAW process using Filler TGS-1CM (AWS 5.28 ER90S-G), Ø 2.4 mm.
6. DPT (dye penetrant test).
7. Final welding using GWAT process.
8. Installing the window by tack welding, that was cut to facilitate.
9. Root pass welding all around the window using Filler TGS-1CM, Ø 2.4 mm.
10. DPT.
11. Final pass welding all around the window using same filler.
12. RT(Radiographic test)

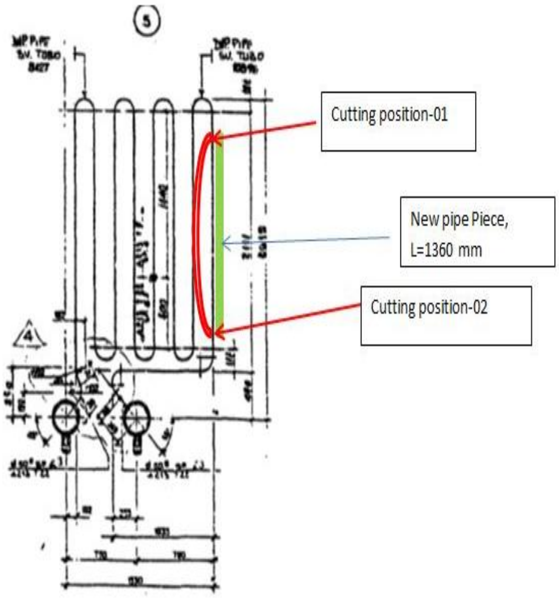


Fig.5: Secondary super heater coil.

6.2 RT and PT Result:

Radiographic test result revealed no linear indication on the weld, several rounded indication & root concavity has been observed. Excess penetration on the root of inner side welding and non-uniform welding profile of both side welding joint were observed. Overall welding condition was not satisfactory. However, all the indications were left for consideration due to extreme access limitation.

6.3 Leak Test with Air

After repairing of coil tube no. 62, couple of leak tests was performed to identify any leakage in the welding work. The test was carried out by air pressure 5 kg/cm2. The result was satisfactory as no leakage was observed.

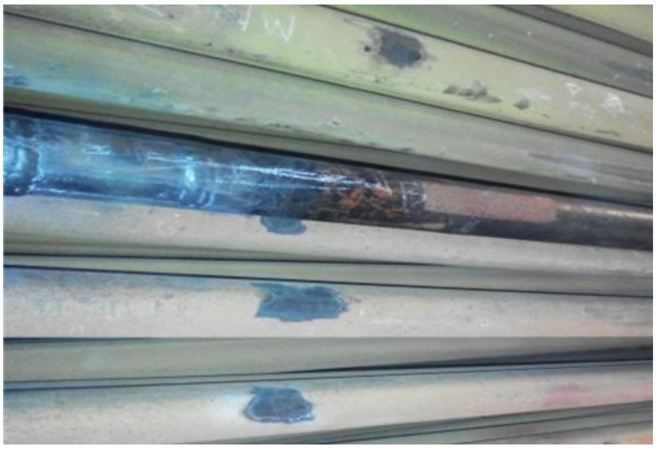


Fig.4: View after short piece welding.

6.4 Hydrostatic Test:

Hydrostatic test was carried out at 116 kg/cm2 by BFW and found okay. Pressure was not increased further, because of the fear that water might leak through the isolating valves and cold water entering into the live steam system could be problematic for the operation of the ammonia plant.

6.5 Boroscopy in both Headers of Superheater Coil Tube, Checking of desuperheater, and pressure safety valves of Steam Drum & Internal of Steam Drum:

Boroscopy test was carried out in both headers but found no blockage inside. Desuperheater was removed and visually checked. Some debris found inside desuperheater header pipe line during boroscopy inspection which was cleaned by vacuum cleaner. Pressure safety valves of steam drum and super heater steam line were checked, calibrated, and re-installed. After steam drum internal checking and performing necessary internal cleaning, the manhole of steam drum was re-installed.

6.6 Hand over:

On completion of restoration work, boiler-1 was handed over for start-up. Burner firing of Boiler-1 was done at 06:30 hrs on 13th December, 2015, earlier water filling was started from 17:30 hrs. When steam pressure rose to 100 kg/cm2, Header of Boiler-1 was lined up at around 01:30 hrs.

7. RESTORATION ACTION

7.1 Background

To make convenient welding position, KAFCO maintenance considers the hot bending of sound portion of the failed tube. The idea is by gas heating, sound portion of tube will be bended to desired angel so that easy welding is possible. Incidentally such repair technique is not common for repair of boiler superheater tube, therefore KAFCO inspection section with the association of KAFCO maintenance department perform a mockup test at one of the spare superheater tube hot bended in KAFCO workshop by using gas burner and investigate metallurgical changes of hot bended tube at KAFCO shop and original manufacturer condition.

7.2 Material Information

Available spare tubes were made into different segments and test was done with the various segments.

Table 2: Spare Superheater tube Specification

Segment	Thickness	Material
1	7.5mm	T22
2	5.70mm	T22
3	4.30mm	T11

Fig.5: Sound elbow and hot bend.

7.3 Hot Bending Procedure

Hot bending was performed by heating up one of the 90^0 Elbow by using oxy-acetylene flame. The heating continued up to $670\sim710^0$C uniformly. One arm of the pipe was fixed firmly and heating was applied on the elbow. When the material reached temperature around 700^0C, free arm of the tube was pressed slowly until the 90^0 elbow turns 35^0. After completion of bending, tension on the tube released and allows the material to cool down in ambient air. Hardness was measured before and after bending action by the help of rebound ball hardness meter. Visual inspection after bending also confirms there is no surface crack on the tube surface. Hardness before hot bending were 105~121 HB, whereas hardness after hot bending were 110~129 HB.

7.4 Microstructures

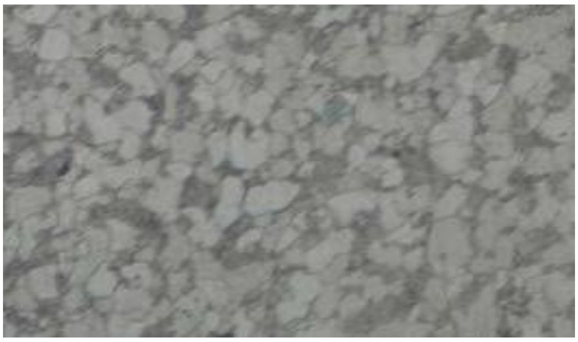


Fig.6: Sound elbow from Manufacturers shop (100X)

Fig.7: Sound elbow from Manufacturers shop (200X)

Fig.8: Hot Bended elbow (100X)

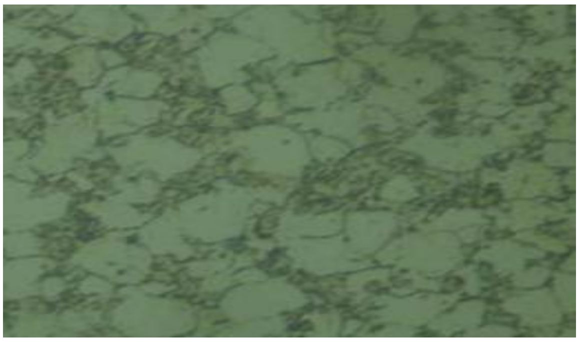


Fig.9: Hot Bended elbow (200X)

7.5 Micro Vickers Hardness Data

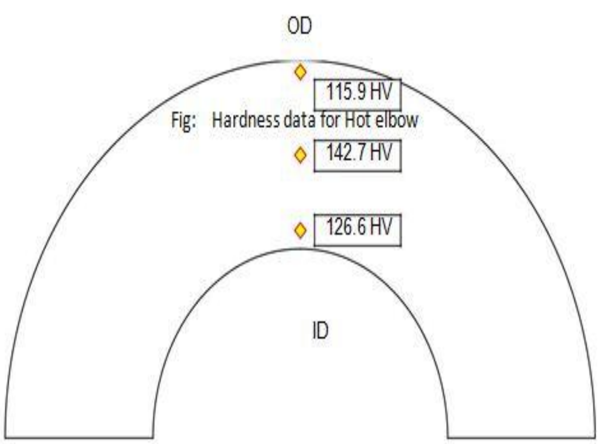


Fig.10: Hardness data for Hot Bended elbow

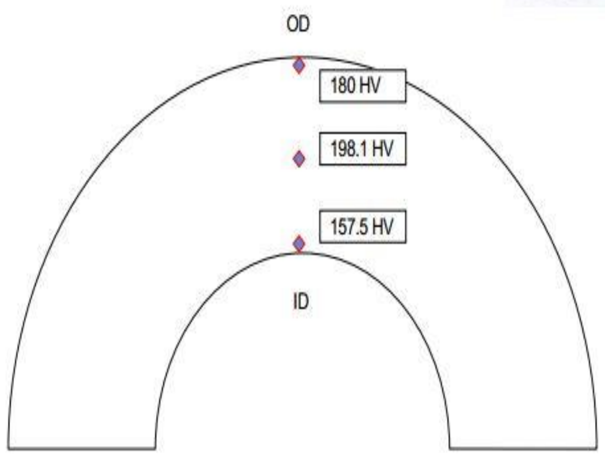


Fig.11: Hardness data for Sound elbow from Manufacturers shop

7.6 Observation

Both hot & sound elbow shows normal ferrite-pearlite type structure. Grain size for both the condition remains same. Any kind of significant difference between these two microstructures has not been observed.

8. RECOMMENDATION

During normal operation both the boilers remain on stream continually at high load for meeting the demand of two steam turbine generators as well as urea and ammonia plant running above rated capacity. Boilers are getting aged and overburdened. Moreover, the recent breakdown and subsequent consequential effect on SH coil of Boiler-1 would hasten the failure of tubes of secondary SH coil. Under such alarming condition, Boiler-1 might not sustain for long time in service. Preventive measures should be in place immediately considering further grave situation that may arise any time. Measures are as follows:

1. Procure a complete set of spare SH coil assembled with headers. It is recommended that, the existing material SA213 T11 of Primary coil should be changed with SA213 T22 as well which is the existing material of Secondary SH tube coil.
2. Ensure availability of spare SH coil as early as possible
3. Follow the safe operating procedure so as to avoid further shock
4. Carry out Metallurgical test particularly creep test of both spare & ruptured tube to assess the tube life at BUET and MACCHI.
5. Conduct inspection in case the Boiler-1 goes to shut down.
6. Conduct any check in case of any abnormalities
7. Keep all preparation associated with coil replacement
8. Plan for setting up one more boiler (boiler-3)

9. CONCLUSION

In this paper, we tried to shed light on the failure analysis of superheater tube by visual site inspection, hardness measurements. Short-term overheating as result of the localized flue gas flow was considered as the failure mechanism. Hardness measurements on the failed rupture region and some distance away region of the as-received tubes were carried out in order to support in determining the failure mechanism. The welding quality of repaired SSH tube is not up to the mark due to access limitation and complex design of super heater coil, the repaired welding fulfilled minimum requirement of acceptance. At present, the boiler is running at pressure around 105 kg/cm^2; however, considering the low quality of the welding joints, the repaired tubes may fail anytime. Hence, immediate replacement of SH coil is required to ensure uninterrupted operation of Boiler-1.

10. ACKOWLEDGEMENT

First Author takes pleasure in expressing gratitude towards Karnaphuli Fertilizer Company Limited (KAFCO), Chittagong and would like to thank the management of KAFCO for their cooperation and support.

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