Paper No.
PPU22

CORCON 17-20 September Mumbai, India 2017

Failure of HRSG tubes during Pre-Commissioning Hydro test

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ABSTRACT

At Kochi Refinery, GT (Gas Turbine) & HRSG (Heat Recovery Steam Generator) was being erected as part of Refinery expansion. During pre-commissioning, hydro test of entire integral piping including boiler banks was done and a leak was observed from tubes. Leak was observed on the fifth hydrotest (one at shop and four at site). During inspection, it was observed that leak was due to external corrosion. Severe pitting was observed. Samples were taken and analysed to identify the root cause for failure. This paper provides the details of failure (MIC & CUI combined) and the type of corrosion and the repair carried out. Paper highlights the importance of proper storage of equipment to avoid such premature failure to avoid moisture ingress.

Keywords: Corrosion Under Insulation (CUI), Microbial induced Corrosion (MIC), Heat Recovery Steam Generator (HRSG), Boiler

INTRODUCTION

The design arrangement of HRSG pressure parts consists of modules connected to steam drum through riser and down comer circuit. Each module consists of finned tubes with bare end welded to headers. As a part of standard manufacturing & construction Philosophy, the modules are manufactured in vendors shop. These modules are hydro tested under the supervision of IBR authority in the factory. After hydro test, the bare portion of the tubes is duly painted & insulated. The modules are properly packed, enclosed in tarpaulin & then shipped to site. The modules are then stored at the site storage facility till they are taken up for erection. Subsequently, the modules are erected as per the erection sequence. Prior to erection, the pressure parts are inspected by local IBR authorities at site.

Typically the modules are ODC (Over dimensional consignment) & hence are transported and stored at site well in advance of erection commencement to ensure their timely availability. The erection cycle time is approximately 7 to 10-months that involves erection of pressure parts and is common practice for the modules to be stored at site for 6-8 months.

These modules were stored at Yard (Cochin) which is approximately 8 kms from site. The modules had to be stored at this location due to non-availability of storage space at site. These modules were wrapped & covered with tarpaulin in storage yard and then were shifted to site 1 to 2 day prior to actual erection. The modules were erected as per the erection sequence and hydro test for entire boiler was successfully conducted. Refer Figure – 1 for typical arrangement. Figure -2 provide details on the sealing arrangement. Table -1 provide details of tubes for each module.

After the total pressure part welding were completed for HRSG, hydro test was conducted internally at a pressure of 183 kg /sq cm which was witnessed by vendor inspector on 24th July 2015, subsequently it was offered to consultant on 25th July 2015. Both the tests were successful and further it was offered to client on 27th July 2015. Finally the hydro test was witnessed by IBR authorities on 5th August 2015. All the above tests were conducted at a pressure of 183 kg /sq cm and no tube leaks were observed.

After the external & interconnecting piping was erected, another hydro test was conducted along with external piping on 27th June 2016. During this hydro test leakage was observed from the module. On further inspection, the source of leakage was identified in economizer module. Thus the first leakage was detected only after 5 pressure tests including 1 at shop & 4 at site. Till that time, all the materials were in sound condition & they could withstand the high pressure

As a first step after the leakage, baffle plates and insulation were removed to access the leakage spot. Inspection of Economiser module revealed pitting of tube which had led to leakage.

To carry out the repair work insulation was removed for nearby tubes also. Pitting was observed in some of these tubes as well, hence inpection was extended to all the accessible areas of modules. It was observed even pitting was there on T91 tubes. Please refer figure-3 for the hole & pitting on T91 tubes. Figure-4 shows some pitting on the economizer tubes.

INVESTIGATION

For further investigation, samples of tubes, rain water and ceramic wool was sent to reputed lab for analysis. The tube sample report indicated failure due to pitting. Ceramic wool properties were found to be matching with the original supply condition properties & no corrosive elements were detected in the wool.

pH values of rain water observed were 5.76 in Refinery premises and 3.88 / 3.40 at storage yard. These values indicated that the rain water was highly acidic

Tube chemical properties, mechanical properties, microstructure of tube material, hardness were tested and found as per original material specification.

Wet ceramic wool and water samples were analysed and it confirmed the presence of high microbial element i.e. sulfur reducing bacteria and iron reducing bacteria. Refer Table-2 for the details on the bacterial count.

Based on peculiar pitting pattern observed on the tube surface, tube sample were analysed for microbiological pitting. After analysis, it was confirmed that the failure of the tube was due to microbial induced corrosion (MIC). Refer Figure-5 for the photos. EDS analysis result are available in Table-3

DISCUSSION AND ANALYSIS

MOC of economizer tube confirms to SA210 Grade A1. Microstructure is banded fine grains of ferrite and pearlite. Hardness values are normal. Hence, the tube metallurgy is considered normal.

Pitting is in cluster form having uneven contours and depth are noticed spread over the outer surface. The depth into the tube matrix is uneven and slanted having spongy appearance due to interconnectedness of small size pits in adjacent surroundings. Along with these features and presence of high level of carbon and sulfur in EDS analysis into the pit, points towards onset of MIC (microbial induced corrosion) damage.

When the contaminated rain water in untreated form comes in contact with the steel surface under stagnant or low flow conditions it tends to promote pitting caused by MIC as the bacteria remaining present in the water get attached to the metal surface. This attachment is followed by colonization (bio- film) generation and formation of deposits. Bio-film formation in form of deposits, starting as a film, subsequently develops as bulky deposit which are called as bio mounds that are more corrosive in nature. They promote under-deposit corrosion by formation of concentration or differential aeration cells that manifest by way of localized attack creating large subsurface cavities and tunnels having uneven contours and depth. It appears spongy in appearance having tubercles at microscopic level. While there are several different types of bacteria promoting MIC, in this case the damage is influenced by acid producing bacteria or sulfur reducing bacteria as carbon and sulfur rich in concentration are noticed in EDS analysis into the pit. Microbes can either fully corrode the steel surface or partially degrade it; the latter allowing steel matrix to spall further by other organisms or chemicals. These characteristic are observed during analysis.

Sulfate Reducing bacteria (SRB) are those bacteria and archaea that can obtain energy by oxidizing organic compounds or molecular hydrogen while reducing sulfate (SO2-) to hydrogen sulfide. There organisms breathe sulfate rather than oxgen in a form on anerobic respiration. The sulfate reducing bacteria reduce sulfate in large amounts to obtain energy and expel the resulting sulfide as waste;

this is known as dissimilatory sulfate reduction. SRB can create problem when metal structures are exposed to sulfate containing water. Interaction of water and metal creates a layer of molecular hydrogen on the metal surface; sulfate reducing bacteria then oxidise the hydrogen while creating hydrogen sulfide, which contributes to pitting.

Iron reducing bacteria (IRB) are bacteria that derive the energy they need to libe and multiply by oxidizing dissolved ferrous iron. The resulting ferric oxide is insoluble and appears s brown gelatinous slime that will stain the surface. They are known to grow and proliferate in waters containing as low as o.1 mg/l of iron.

CONCLUSION AND PREVENTIVE MEASURES

No specific pattern of pitting was observed on the tubes and this pitting was found to be taking place at random. It can be concluded for above analysis that failure has occurred due to MIC.

Root cause for failure is the ingress of rain water & its presence for a long duration in the ceramic wool insulation during storage & erection. Also the quality of paint is also to be ascertained as the paint was applied considering the operation philosophy. Protection during storage period was not considered (against CUI) while selecting the paint. Hence it is important to ensure that such system has proper painting and sealing till the completion of erection to avoid such failure in the future.

REFERENCE

1. Vendor analysis report 2016/BPCL Cochin dated September 26, 2016
2. Various lab reports
3. Microbiologically influenced corrosion book by Reza Javaherdashti
4. Microbiologically influenced corrosion handbook by Susan Watkins Borenstein

Figure – 1 : General layout of Modules

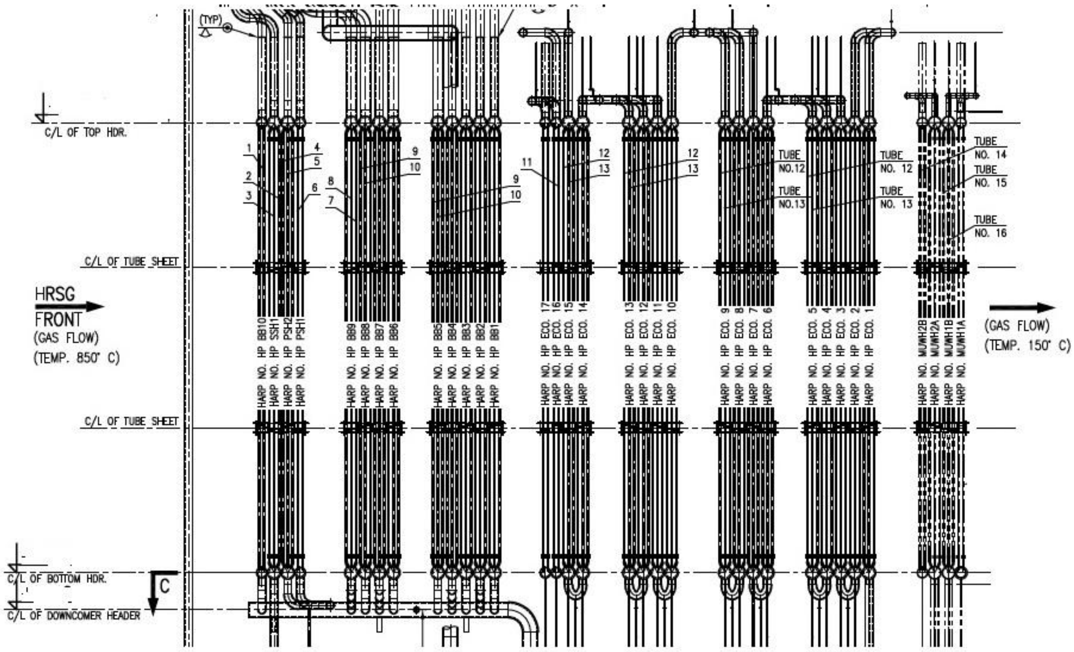


Figure – 2 : Sealing arrangement of Modules

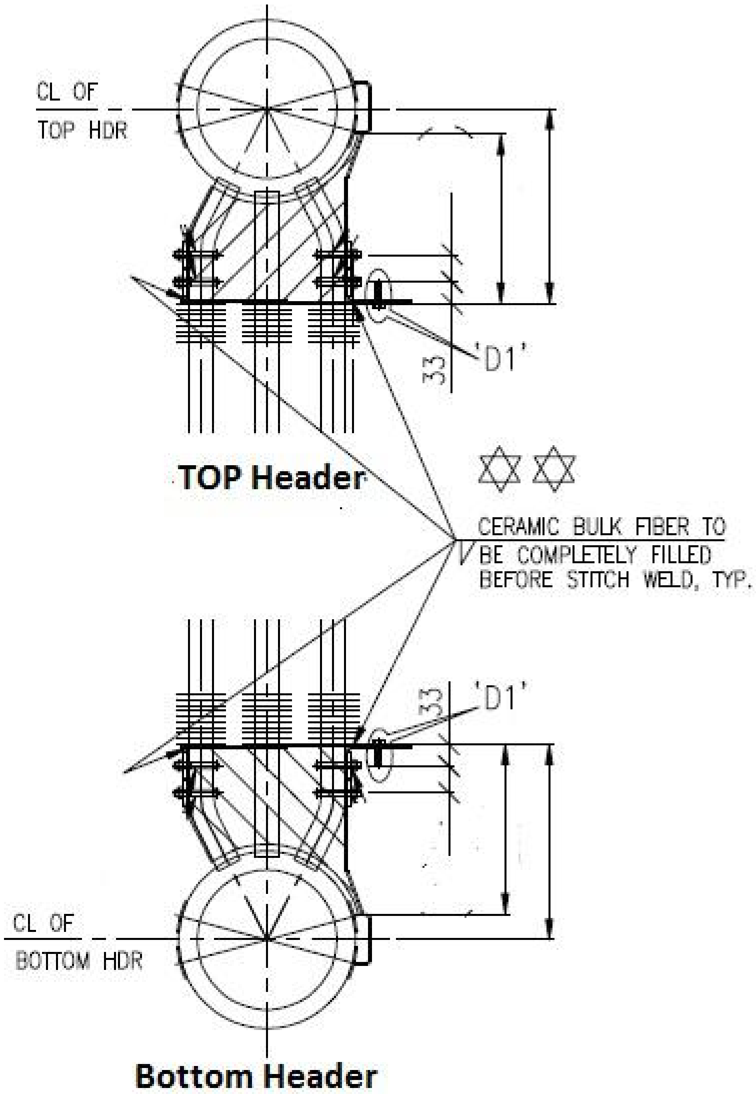


Figure-3 : Super heater tube, T91, pin hole & pitting

Figure 4 : Economiser tube pitting

Figure 5: Economiser tube detailed analysis

Shows close-up view at one such location of pits. They appear to be in cluster form having uneven contours and depth. Pit surface looks blackish in appearance.

Shows inner surface view after sectioning. It is having adherent scale.

SEM images

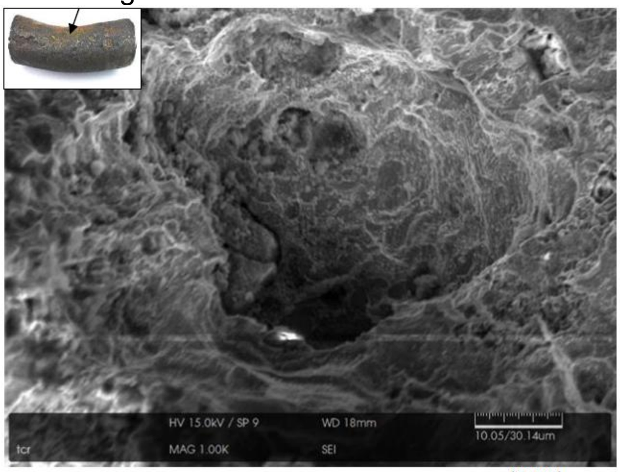


Plate: 8 *Outer surface* *(1000X)*

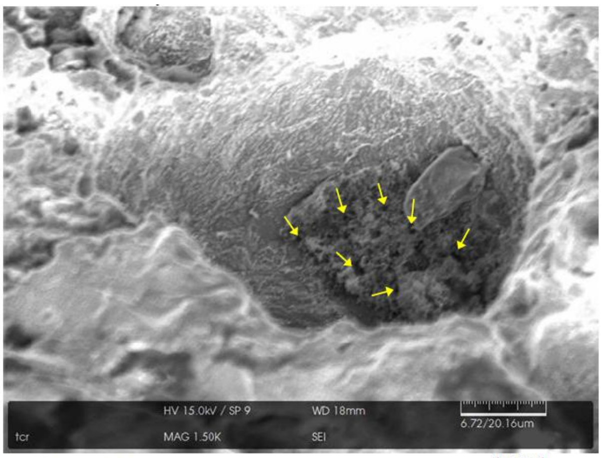


Plate: 9 *Outer surface* *(1500X)*

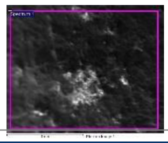
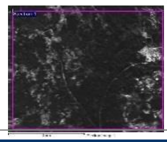
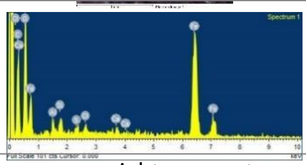
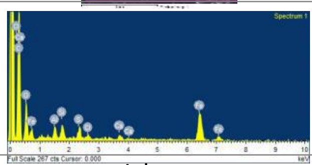
Table 1: Tube Details

	Tube material	OD	Thickness
PSH1	SA213 T11	38.1	3.25
SSH	SA213 T91	38.1	3.25
PSH2	SA213 T11	38.1	3.25
BB1 to BB9	SA210 Gr A1	38.1	2.7
BB10	SA210 Gr A1	38.1	2.7
ECO 1 to 17	SA210 Gr A1	38.1	2.7
MUWH 1A, 1B, 2A, 2B	SA213 TP304	38.1	2.7

Table 2: Bacterial Count

Water Sample		
IRB	Present	
SRB	900	MPN in 100 ml
Ceramic wool (wet)		
IRB	130	MPN in 100 ml
SRB	240	MPN in 100 ml

Table 3: EDS Analysis on various locations on outer surface

	On outer surface	On pit
		
		
		
Elements	weight per cent	weight per cent
Carbon	13.23	44.02
Oxygen	12.95	12.94
Aluminum	1.57	2.52
Silicon	1.47	2.75
Sulfur	0.96	2.06
Chlorine(Chloride)	0.80	1.16
Calcium	0.45	0.87
Iron	68.57	33.67

Remark: The presence of high amount of carbon and sulfur is noticed.