Root Cause Analysis of Tube Leakage for an Ammonia Converter Effluent Cooler / Steam Generator

Heat Exchanger World Conference & Expo Americas 2022

Presented by:

Jerry Zhang, Sr. Technical Advisor, Proprietary Process Technologies & Equipment

Patrick Guy, Director-Engineering Operations, Proprietary Process Technologies & Equipment

Abstract:

This paper shall detail the inspection, analysis and root cause determination of tube leakage experienced on an Ammonia Converter Effluent Cooler / Steam Generator. This paper is intended for both ammonia plant operators and heat exchanger manufacturers.

Some tubes were found choked, corroded and perforated at high flux locations resulting in leaks which necessitated the shutdown of the plant to address.

Due to the urgent need to return the plant production, special considerations were required to learn as much as possible in the shortest amount of time. The paper shall detail these considerations which included cleaning, inspection and testing. Inspection activities further revealed metallurgical concerns at suspected areas and pointed to what corrections needed to be addressed along with BFW quality analysis determinations. Secondary affects due to the tube leakage were also determined and will be appropriately cast in the paper's findings.

The paper further delves into suspected assembly and handling issues which are evidenced by damaged, kinked and otherwise deformed tubes in proximity to leak locations. Such physical elements disturbed BFW/steam flow patterns during operation. The paper will also assert in detail the correlation of physical damages and the high flux at these locations and the resultant issues (fouling, deposits, corrosion, dry tube, etc..).

The paper will conclude with a summation of all issues experienced along with recommendations provided to the plant.

Problem Findings:

KBR received request for help from one of our clients to identify the root cause of the Ammonia Converter Effluent / Steam Generator tube leakage. This heat exchanger experienced leakage after placed into service for about one year.

Design Condition:

	Design Pressure kgf/cm2(g)	Design Temperature °C
Shell side	171.5	500/-12
Tube side	146	346 / -12

Service of this heat exchanger:

Shell side: Ammonia converter effluent; Tube side: BFW / Steam

HEAT EXCHANGER WORLD CONFERENCE & EXPO AMERICAS

2022

Materials of Construction:

Channel Side:

Channel Shell	SA336 F11 Cl.3
Tubesheet	SA336-F22 Cl3*
Channel Flange/Cover	SA336-F11 Cl.3
Tubes (19ODx3.05 thk.)	SA213 TP321

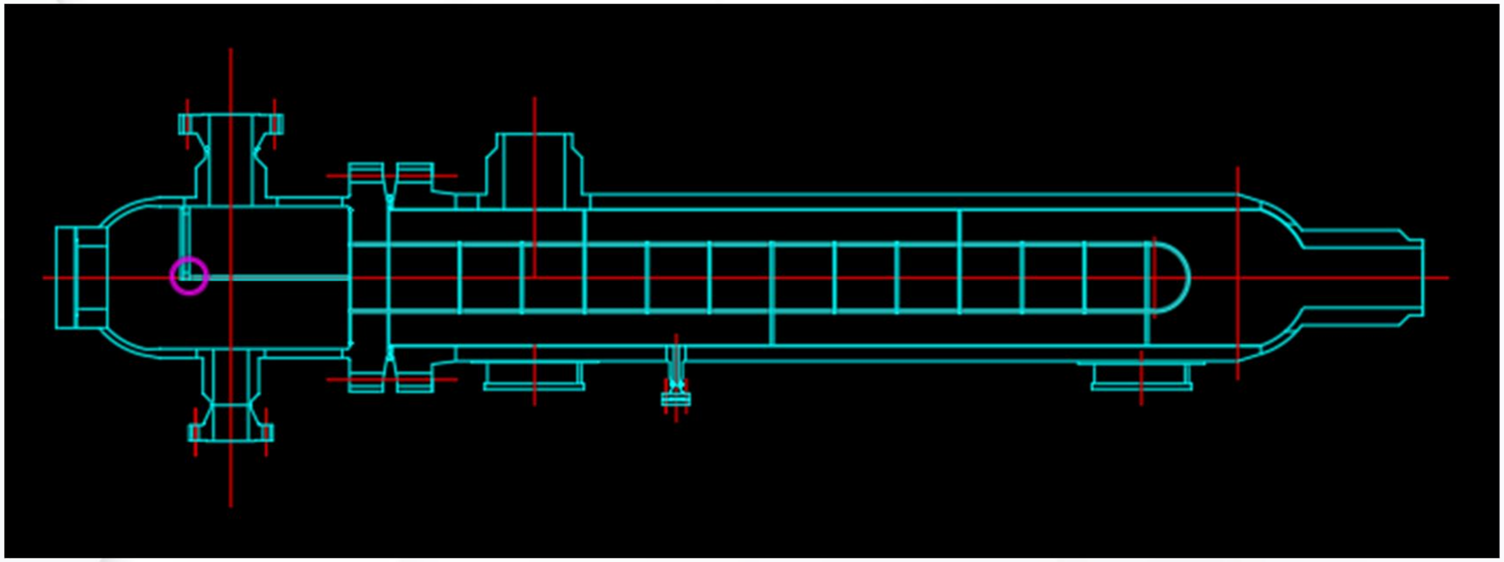
Shell Side:

Shell	SA336 F22 Cl.3
Shell Cover	SA336 F22 Cl.3 *
Expansion Bellow @ nozzle inlet	Alloy 600
Lip seal gasket	Alloy 600

* WITH OVERLAY INCONEL 600

HEAT EXCHANGER WORLD
CONFERENCE & EXPO
AMERICAS

2022



General Arrangement
Ammonia Converter Effluent Cooler / Steam Generator

Problem Description:
The Ammonia Converter Effluent Cooler / Steam generator experienced failure (tube leakage) after put into service for about 1-year (within manufacturer's warranty), both KBR and the client wanted KBR to provide RCA (Root Cause Analysis) on the failure of this heat exchanger based upon the observations and limited tests and examinations.

After plant was shut down, the following activities were performed according to client:
1. Performed leak test on the exchanger tube side, it was found massive leakage of tubes, pressure cannot be held at channel side; This indicated mass leakage in tubes;
2. Client did not want to remove tube bundle due to the complexity of lip seal and client want to have quick turnround if possible.

Utilization of a Borescope was suggested to identify leaked tube exact locations, after removing channel cover, it was found some tubes are heavily choked. This same phenomenal are also found in one other heat exchanger from a client as well for the similar service conditions.

The Borescope probe cannot be inserted for examination into some tubes due to the heavy deposits inside tubes. Mechanical cleaning of the tubes including hydro jetting were done in order to check the leaking tubes.

Borescope images indicated root line along inside tubes, such area are corresponded to shell inlet gas at first baffle turn, those area are high flux area. Borescope images cannot be displayed at this moment. The Borescope image looks very similar to Caustic gouging along a longitudinal water line. See below sketch from a book regarding Caustic corrosion.

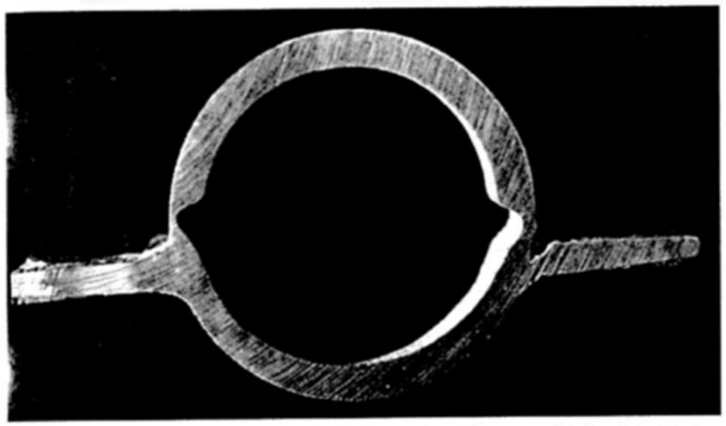


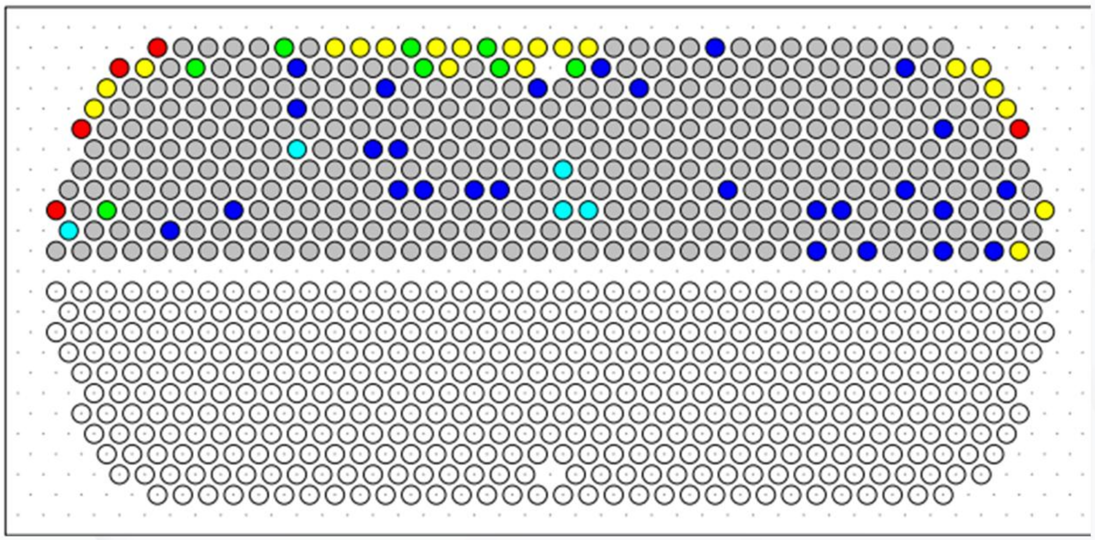
Figure 4.4 Caustic gouging along a longitudinal waterline. *(Courtesy of National Association of Corrosion Engineers.)*

Caustic Corrosion Definition:

Locations

Generally, caustic corrosion is confined to (1) water-cooled tubes in regions of high heat flux, (2) slanted or horizontal tubes, (3) locations beneath heavy deposits, and (4) heat-transfer regions at or adjacent either to backing rings at welds or to other devices that disrupt flow.

ECA (Eddy Current Array) have been done as well in order to check all the tubes condition, below is the mapping of tubes with defect tube location in related to tube layout.



0	PLG: Plugged	27	20 < Defect <= 40
5	80 < Defect <= 100	5	0 < Defect <= 20
20	60 < Defect <= 80	345	No Defect Detected
8	40 < Defect <= 60	410	Not Tested

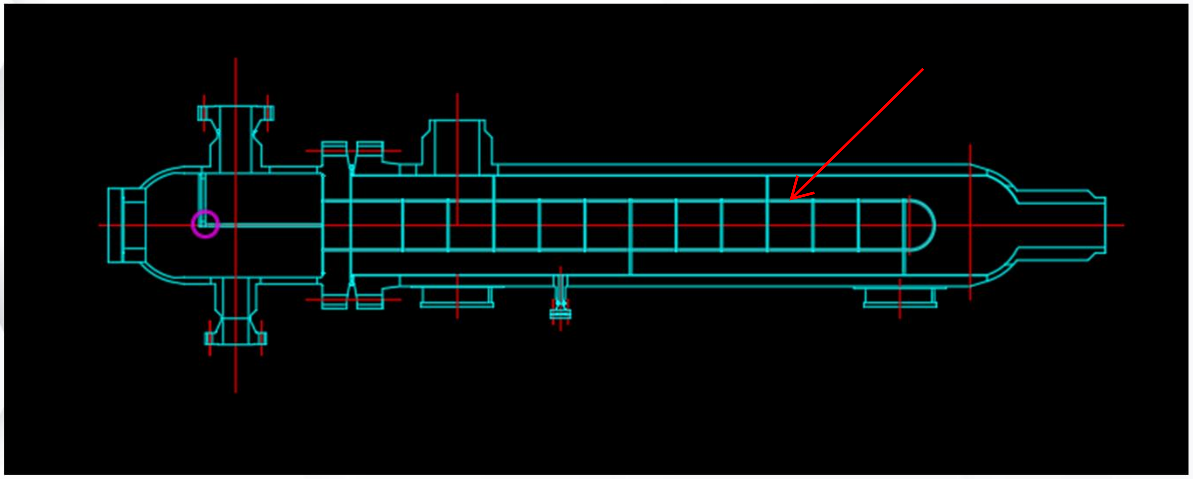
According to KBR Datasheet

) HEAT RELEASE CURVE

S.No	DUTY	GAS	BFW / STEAM			DELTA-T	VAPOR	
	GCAL/HR	°C	T, °C	KG/SQCM	h, KCAL/KG	°C	%	
1	15.1083	459.0	330.8	132.53	0.000	128.2	14.39	
2	13.8493	452.3	330.9	132.62	401.085	121.4	10.793	
3	12.5902	445.5	330.9	132.70	397.248	114.6	7.195	
4	11.3312	438.8	331.0	132.78	393.412	107.8	3.598	BOILING POINT
5	10.0722	432.0	331.0	132.87	389.576	101.0	0	
6	8.8132	425.2	331.1	132.95	385.739	94.2	0	
7	7.5541	418.4	331.1	133.03	381.903	87.3	0	
8	6.2951	411.6	331.2	133.12	378.066	80.5	0	
9	5.0361	404.8	331.2	133.20	374.230	73.6	0	
10	3.7771	398.0	331.2	133.28	370.393	66.7	0	
11	2.5180	391.2	331.2	133.37	366.557	59.9	0	
12	1.2590	384.3	329.0	133.45	362.720	55.3	0	
13	0.0000	377.5	326.7	133.53	358.884	50.8	0	

According to KBR design, around 14% evaporation is expected, but, according to client operation data, evaporation ratio is over 35%, after further investigation, it is found out that BFW flowrate is less than KBR process design which indicated BFW starve in this heat exchanger. Short of BFW caused higher evaporation rate at the local high flus area where damaged tubes are located.

The damaged tubes are located at the below location where arrow pointed, damaged tubes are located at outer perimeter of the tube.



Those damaged tubes are located at high flux area where syngas inlet toward first baffle turn area.

KBR requested the client to provide BFW analysis report as well, After analysis of that data, it was found this heat exchanger experienced low BFW supply for an amount of time and additional BFW was supplied to adjacent heat exchangers. These conditions make the evaporation rate on this heat exchanger higher than designed. This higher evaporation ratio leads to the precipitation of solids and chemical deposits on the partially "dried" tubes. Further chemical analysis indicated the PH value in BFW changed as well.

BFW Analysis Data also revealed that sodium, phosphate and silica are significantly lower at BFW outlet nozzle as compared to the measurement at inlet nozzle.

This indicated all those elements are formed to chemical compounds and deposit inside tubes , the higher flux area have more chemical deposit which found the choked tubes.

The BFW analysis shows a significant reduction of phosphate, sodium, silica, sulphate at the outlet of BFW which indicates chemical precipitation/deposition inside tube wall.

The Borescope images in the tubes (after cleaning of the tubes) reveals that "caustic gouging" had been caused by the reaction of sodium phosphate species with the boiler tube steel, boiler tube oxides or both. Caustic corrosion produces well-defined depressions or gouges, as does phosphate attack at lower sodium-to phosphate ratios.

KBR recommended that the client take a metallurgical sample from the damaged tubes for a detailed metallurgical analysis during next turn-around in order to arrive at definitive root-cause of the leakage.

According to the ECA report, there are (5) five tubes which have wall loss approaching 100%. Most of the tubes with wall loss are near fourth baffle, as counted from the U-bend which is shown in previous sketch. After discussing this with the heat exchanger manufacturer, it is reported that the baffle holes exceed TEMA limits. According to the manufacturer's inspection report, another factor is possibly due to tube bundle insertion.

The baffle where the damaged tubes are located can get kinked during bundle insertion, such damage can occur at vendor's shop. Tube kinks change the shape of tubes, which can accelerate the tube wall damage during operation. Meanwhile, oversized tube holes in baffle might cause unexpected vibration/knocking at the tubes' baffle.

The ammonia leak into BFW from damaged tubes increased the pH value of BFW which increased the caustic corrosion as well.

Conclusions:

The tubes failed due to a combination of the following:

1. BFW starvation increased the evaporation ratio at local high flux area(s) which caused local boiling, the chemical deposit formation at the local boiling area especially at the interface between BFW and steam which led to caustic corrosion;
2. Tubes are “kinked” during the bundle insertion which the deforms the tube and results in failure of tubes in these locations;
3. Oversized tube holes at baffle (exceeding TEMA guidelines) contributed to tube vibration. Movement and contact of the tubes inside the enlarged baffle holes caused the outer tube thinning, likely accelerating the damage process from outside of tubes;
4. Ammonia entered into to BFW stream from the leaked tubes which changed pH value of BFW, accelerated the caustic corrosion process, the main reason failure is due to caustic corrosion at inside of tubes.

The damaged tubes are plugged according to tube plug procedure provided by manufacturer and plant are back to production, future metallurgical analysis in damaged tubes are recommended. KBR also suggest client seek help from BFW treatment specialist to control BFW quality for normal operation.

Client is advised to perform metallurgical test on damaged tubes during next turn around for further investigation.

References:
Handbook of Materials Failure Analysis with Case Studies from the Chemicals, Concrete and Power industries, 2016

Acknowledgements:
Special thanks to Patrick Guy who provided encouragement and guidance in the submittal of this presentation.

QUESTIONS?