

Stress Corrosion Cracking in Co_2 Compressor Intercooler

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***Abstract*:- In Urea Plant third stage intercooler of CO_2 compressor heat exchanger made of type SS-304L stainless steel at a National Fertilizer plant about 50 numbers of tubes developed cracks due to stress corrosion cracking. In this articles described how to developed SCC in austenite steel in Chloride contents more than 50 ppm at 50^0C. Stress corrosion cracking can be considered as a form of localized corrosion with complex mechanical and electrochemical interactions taking place in the crack and at the crack tip. Cracking may be inter granular or Trans granular. This phenomenon observed at below 50^0C and low pH. Low pH due to leakage of CO_2 and mixed with cooling water, at low pH the susceptibility of cracking increases.**

Keywords:- Stress corrosion cracking, stainless steel, chloride.

INTRODUCTION

National Fertilizers Ltd, (NFL) operates a fertilizer complex at Vijaipur, Distt. Guna (Madhya Pradesh) consisting of two units Vijaipur-I and Vijaipur-II, plants were commissioned in December 1987 and March 1997 respectively. Ammonia Plants are based on M/s. HTAS's Steam Reforming of Natural Gas and Urea plants are based on M/S. Saipem's Ammonia Stripping technology. The Vijaipur unit, which is an ISO 9001:2000 & 14001 certified, comprises of two streams. The Vijaipur have two ammonia plant M/S. Haldor Topsoe Technology, Denmark capacity 1750 & 1864 TPD for Line-I & line-II respectively and four urea plant of M/S.Saipem In Urea plant 31 unit CO_2 compressor 3rd stage intercooler tubes were got damaged due to stress corrosion cracking on 5/09/2017 The problem analysed and repaired the tubes by replacing the tubes.

EVENT DESCRIPTION

In National Fertilizers Ltd Vijaipur is using BHEL (Bharat Heavy Electrical Ltd.) made CO_2 compressor and turbine. Steam turbine driven centrifugal CO_2 compressor is one of the critical equipment's of urea plant, which compresses the CO_2 gas from 1.4ata to160 ata pressures in four stages. Compressor consists of two halves stiffly bolted together on the horizontal center plane. In between the stages the gas is cooled down in intercoolers and moisture is separated in moisture separators which are vane type design compounded with demister pads**.** Compressor with L.P stage the casing in two halves horizontally split having two stages and 2nd stage having two stages the compressor has two back to back stages. The casing of compressor is barrel shape; closed at the ends by two vertical flanges each stages discharge having intercooler. The diaphragms make up the separating wall between each compression stage. Each diaphragm constitutes a diffuser which converts the kinetic energy of the gas at the out let of the impeller in to pressure and the recover passage which lead the gas to the suction of the next impeller. A series of guide vanes inside the recovery passages axially pipe the gas flow and distribute evenly to the suction of the impeller. The diaphragm manufactured from high strength cast iron. The upper halves diaphragms are fixed to upper half casing by means screws. The stages wise Pressures are following
1st stage-5.5-6.0 kg/cm^{2}g ,2nd stage-22-23 kg/cm^{2}g,3rd stage-87-88 kg/cm^{2}g and final stage 160-161 kg/cm^{2}g and temperatures are 1st stage disch-190^{0}C,2nd satgedisch-182^{0}C,3rd stage-175 and final discharge temperature 120^{0}C the diagram as shown in the figure-1
On dated 05/09/2017, the 3rd stage intercooler of CO2 Compressor tubes were got damaged by stress corrosion cracking. The deep study was conducted with objective of how to developed crack on tubes.

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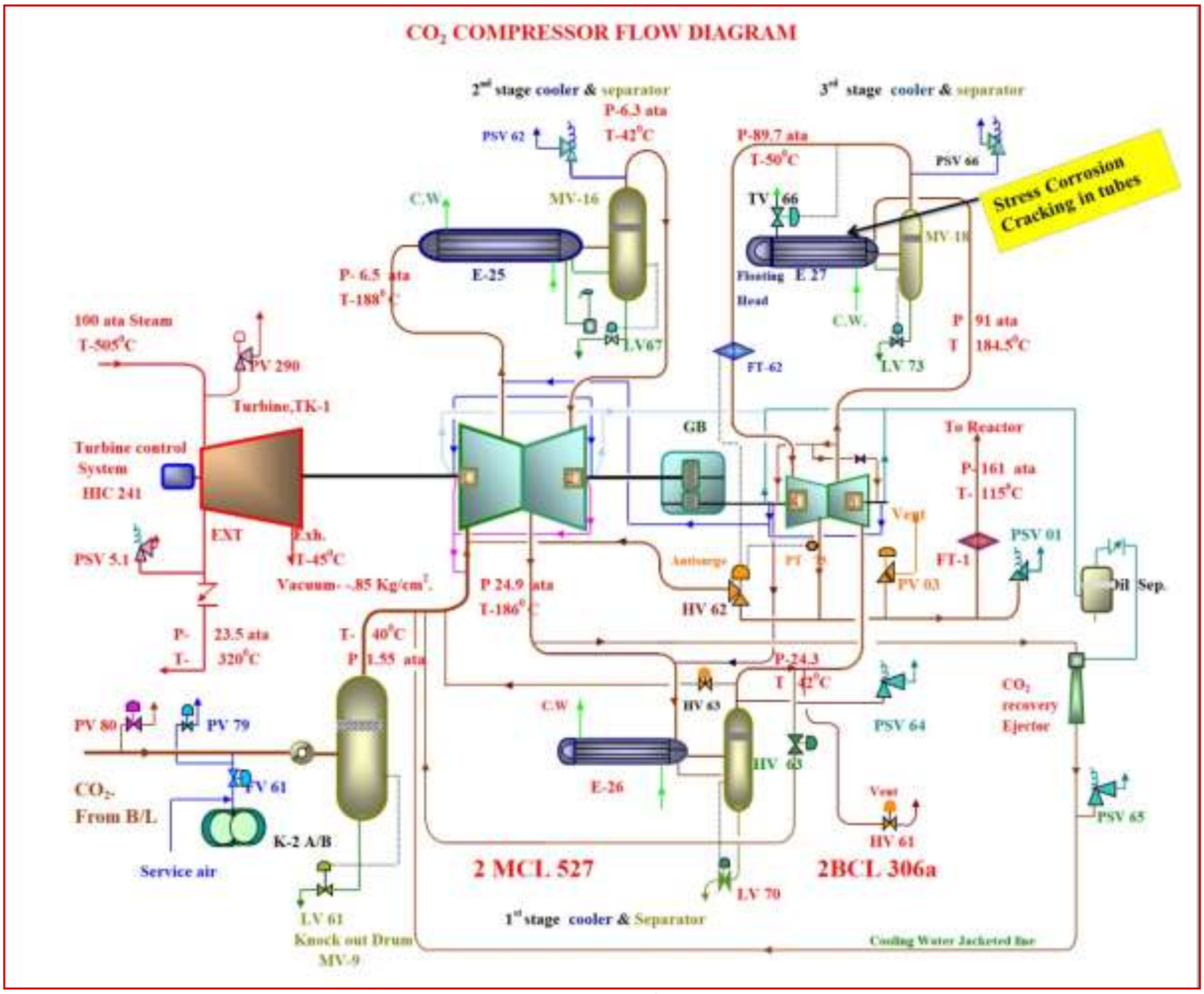

Fig-1(process Flow diagram of CO_2Compressor)

Heat Exchanger(31-E-27) detail			
Sr. No.	Parameters	Shell Side	Tube side
1	Fluid	Cooling water	CO_2
2	Inlet Temperature, ^{0}C	36	182
3	Outlet Temperature,^{0}C	70	50
4	Pressure, kg/cm^2	4.0	87
5	Surface Area, M^2	90	90
6	Total No. of Tubes	226	
7	No of Pass	2	1
8	Tube Length, mm	6600	
9	Tube ,ID, mm	17	
10	Tube OD, mm	20	
11	Pitch, mm	25,Sq.	
12	Heat duty, K.Cal/hr	2114850	
13	MOC	CS, 516Gr70	304L

Table-1(Heat Exchanger Detail)

THEORY BEHIND CRACKS DEVELOPED IN TUBES.

The intercooler tubes made up of SS-304L(Cr-18%Ni-8.0%), the SS-304L is a type of Austenite stainless steel. The addition of nickel has a beneficial influence on the corrosion resistance of ferrite steels. But the Nickel affinity to connect with chlorides and make Nickel chloride and HCl and some minor impurity in metal like sulphur causing stress corrosion cracking. In CO_2 compressor 3rd stage intercooler tube side having CO_2 and shell side having cooling water. The presence of some impurity like sulphur and chlorine in a moist environment at elevated temperatures Stress corrosion cracking is an electrochemical oxidation-reduction process, which occurs within localized deeps on the surface of metals coated with a passive film. This is true the higher nickel (and molybdenum) content makes type 304L/316L more resistant to SCC but 304L there is no molybdenum contents. Anodic reactions inside the crack. This reaction due the damaged of passive film inside shell side of heat exchanger by low p^H in initial stage of minor leakages. The Heat exchanger was opened and examined the tubes deposition scrapped and sent to lab for analysis of yellowish deposition (as shown in the figure-3) - found following result-

$NiCl_2$-17.3%, HCl-12%, Fe(OH)2-11.4%,Ophosphate-7.8%,ZnO-3.7%,Rest-Iron Oxides and silt. The chemical reactions are as following.-

Fe = Fe2+ + 2e- (dissolution of iron).The electrons given up by the anode flow to the cathode where they are discharged in the Catholic reaction:

$\frac{1}{2} O_2 + H_2O + 2e^- = 2(OH^-)$

As a result of these reactions the electrolyte enclosed in the pit gains positive electrical charge in contrast to the electrolyte surrounding the pit, which becomes negatively charged. The positively charged pit attracts negative ions of chlorine Cl^- increasing acidity of the electrolyte according to the reaction:

$FeCl_2 + 2H_2O = Fe(OH)_2 + 2HCl$

$Cl_2 + Ni = NiCl_2$

$\mathbf{NiCl_2+2H_2O=Ni\ (OH)_2 + 2HCl}$

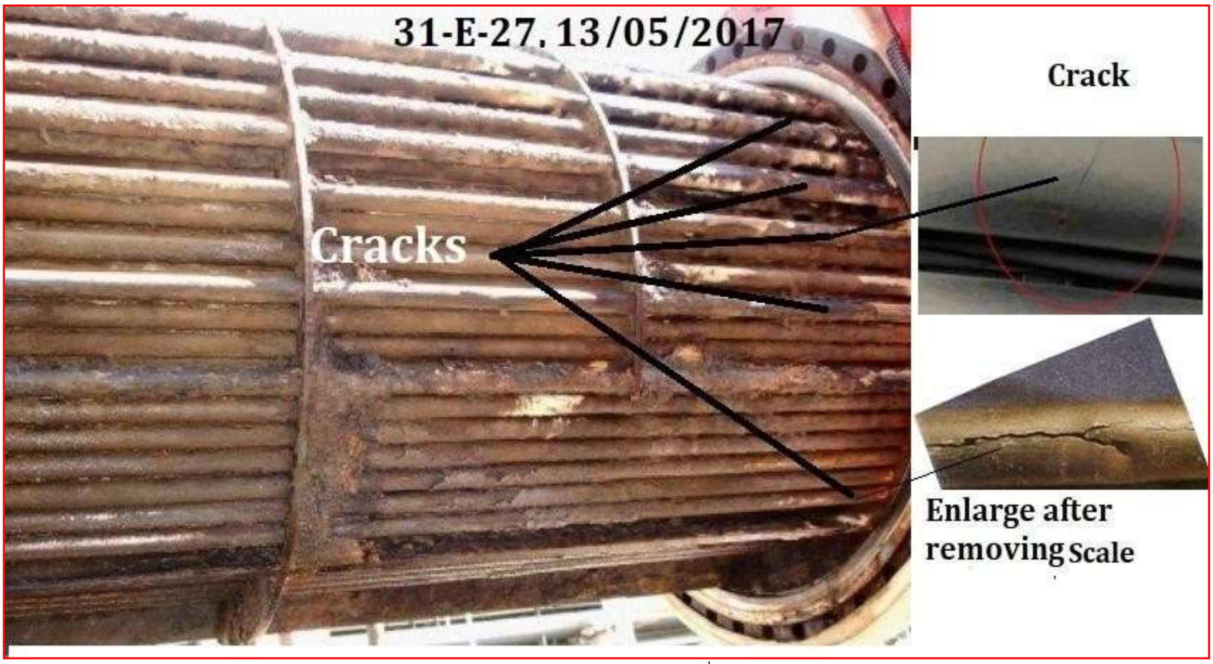

Fig-2 (31 E-27 CO2 3rd stage intercooler)

In initial stage of tube leakages, the tube side CO_2 mixed with shell side cooling water to formed carbonic acid and leading to acidic environment as following reaction. The gas CO_2 is quite soluble in water in which more than 99% exists as the dissolved gas and less than 1% as carbonic acid H_2CO_3, which partly dissociates to give H^+, HCO_3^-, and CO_3^{2-}. The subsequent contributions deal with the central role CO_2 whereas here we restrict ourselves to the reaction between CO_2 and water.

$CO_2 + H_2O=H_2CO_3$

P^H of the shell inside the shell side decreases from 7.2 to 4.5, which causes further acceleration of corrosion process. Large ratio between the anode and cathode areas favours increase of the corrosion rate. Corrosion products Fe $(OH)_3$ form around the pit resulting in further separation of its electrolyte. Due to high pressure and temperature at low pH cracks were developed on tubes. Mechanical damage of the passive film was caused by scratches. Anodic reaction starts on the metal surface exposed to the electrolyte. The passivity surrounding surface is act as the cathode. Non-homogeneous environment may dissolve the passive film at certain locations where initial pits form.

Fig-3 (deposition on shell side)

Sr. No.	Type of Steel	Cr,%	Ni,%	Mo,%	Mn,%	C,%	Si,%
1	AISI 316	16-18	10.0-13.0	2-3	2	0.08	1.0
2	AISI 304	18-20	8.0-10.0	---	---	0.08	1.0
3	AISI 304L	18-20	8.0-10.0	---	2	0.03	1.0
4	Duplex SS	22-23	**5.0-6.0**	2-3	1-2	0.03-0.05	0.35-0.4

Table-2(Stainless steel constituents)

		Date	08/05/2017
Sr.No.	Parameters	Value	Unit
1	pH	7.0 – 7.3	
2	Turbidity	21.6	NTU
3	Conductivity	1850	µS/cm
4	Free Cl2 as Cl_2	0.39	mg/l
5	Phosphate as PO4	4.8	mg/l
6	Total Alkalinity as CaCO3	226	mg/l
7	Total Hardness as CaCO3	773	mg/l
8	Ca Hardness as CaCO3	562	mg/l
9	Mg Hardness as CaCO3	248	mg/l
10	Silica as SiO_2	97	mg/l
11	Total Ammonia As NH_3	36	mg/l
12	Chloride as CL	198	mg/l
13	Sulphate as SO_4	-	mg/l
14	Iron as Fe	-	mg/l
15	Zinc as Zn	0.23	mg/l
16	Cycle of concentration MgH	7.3	

Table-3(Cooling water analysis)

Stress Corrosion Cracking (SCC) is the progressive cracking of metals and alloys caused by the combined effect of SCC-Prone Microstructure, Temperature, Pressure and environments .Tensile Stresses High Enough to Induce SCC: sources of stress: SCC-Facilitating Environs: chloride, hydroxide, carbonate, bicarbonate, ammonia, aerated water, acetate, thiosulphate, phosphate, polythionate, and methanol. Temperature and Time exacerbate the effect of all the above causes. Acting alone, stresses or corrosive ambiences cannot induce SCC. SCC-infested metals demonstrate trans-granular or inter-granular cracks as shown in the figure-4.The affected material may fail without displaying any symptoms of an impending failure. Cracks penetrate deep into the material while the surface remains unaffected and the material fails with meager loss of material.

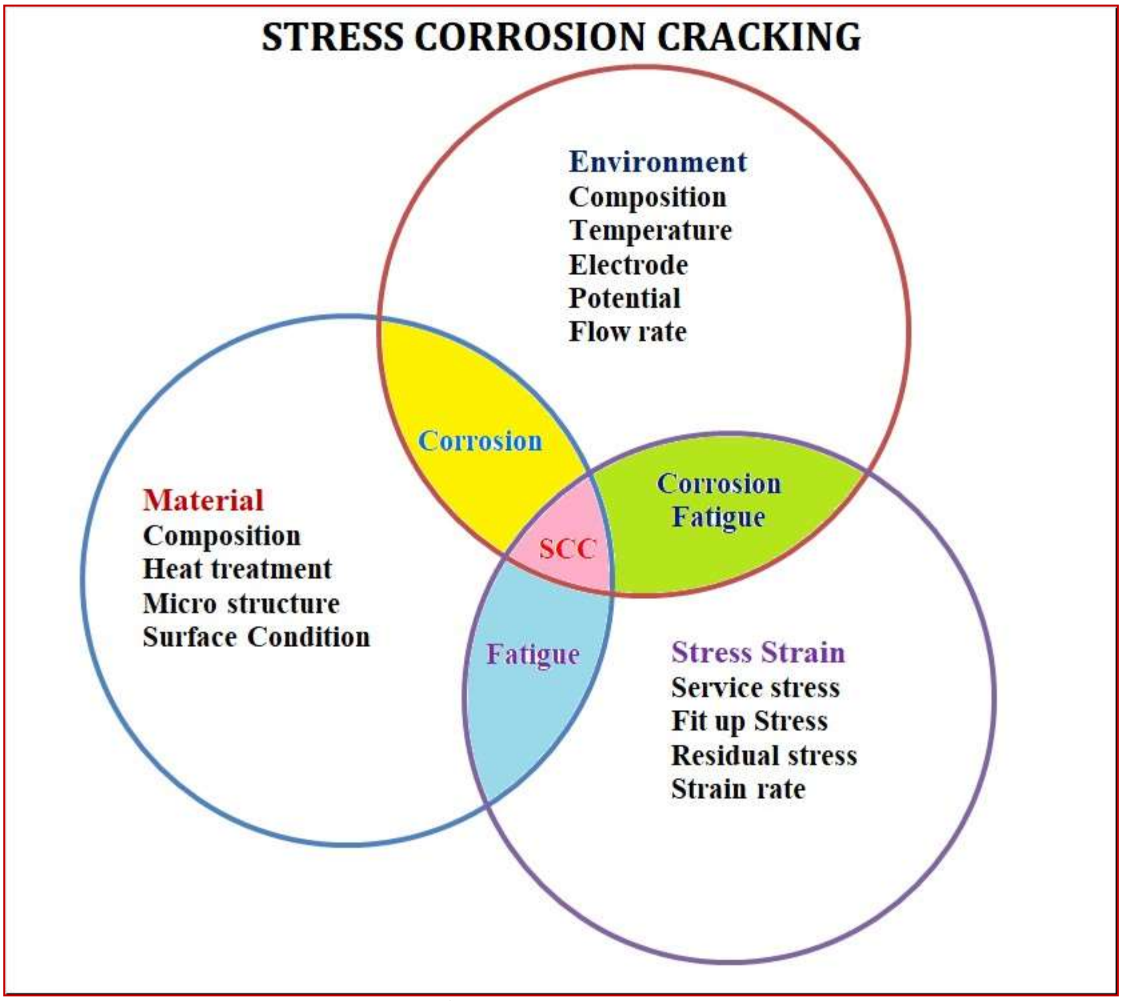

Fig-4 (SCC demonstration diagram), taken from http://www.kemplon.com/wp-content/uploads/2014/10/logo.png.

CONCLUSIONS:

The SS 304L stainless steel tube cracked by trans granular stress corrosion cracking due to the presence of some impurity like sulphur and chlorine in a moist environment at elevated temperatures. The cracked tube section exhibited an equated microstructure without any evidence of sensitization or other material deficiencies. This is true the higher nickel (and molybdenum) content makes type 316/316L more resistant to SCC. In 304L molybdenum contents is zero. But in sample the Nickel Chloride found more. This is the evidence of Nickel contact with chloride made acidic environment and due to high pressure and temperature cracks are developed. Vibration also found in the equipment this can also lead to cracking.

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