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Failure analysis of 6” spool of Process Gas Compressor cooler outlet at Offshore Process Platform

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Abstract:

In offshore process complex, process gas compressors are used to compress gases from 6-8 kg/cm^2 to 90- 96 kg/cm^2 in three stages. The compressed gas is cooled by passing it through inter coolers and the condensed water is removed through the knockout drums (KOD) at the respective stages. This case study pertains to failure of 6”Φ pipe spool segment of third stage cooler outlet line. PGC cooler outlet, after 3rd stage, have a pressure of 92 Kg/cm2 and it has 3.26% CO_2, 90 ppm H_2S along with condensate.

Laboratory investigations of failed PGC cooler outlet showed that chemical composition, tensile strength and hardness value of the tested sample were complying with the SSC resistant, ASTM A 106 Grade B material. The piping had an acceptable microstructure of normalized ferrite and pearlite.

Visual inspection of the failed surface showed the classic sand dune like surface contours oriented along the direction of fluid flow that is typical of erosion-corrosion. In metallographic studies, small pits were observed at several places. EDS analysis of pitted region on failed piping surface confirmed the influence of corrosive species like chloride and sulphides. Localized metal loss of cooler outlet piping led to its failure by erosion corrosion under corrosive environment. All the corrosion studies showed that existing metallurgy of piping was susceptible to CO_2 corrosion. It was recommended to use UNS 31603, 316 L Stainless steels for PGC cooler outlet lines to avert such failures in future.

Key words: process gas compressors (PGC), Flow Assisted Corrosion, erosion-corrosion.

1.0 INTRODUCTION

In offshore process complex, process gas compressors are used to compress gases from 6-8 kg/cm2 to 90- 96 kg/cm2 in three stages. The compressed gas is cooled by passing it through inter coolers and the condensed water is removed through the knockout drums (KOD) at the respective stages. In 2015, 6"Φ pipe spool segment of third stage cooler outlet line, connecting dischaerge KOD, bursted suddenly which resulted in gas leakage and tripping of the compressor.

The failed piping was subjected to various laboratory investigations to check the material integrity as well as to understand the failure mechanism. The details of the PGC Cooler outlet Lines and operating parameters are given below in table-1.

TABLE 1: Details of the PGC Cooler Outlet Lines

Piping specification:	NACE/ ISO 15156 compliant ASTM A 106 Grade B material
Date of commissioning:	21.10.2012
Date of failure:	06.12.2015
Compositional analysis of gas : -indicating CO_2, H_2S and H_2O content	CO_2 - 3.260 %, H_2S - 90 ppm, H_2O - 0.23%
Operating pressure, temperature and gas/oil/water flow rate	90 KSC 56˚C 2.3 MMSCMD
Design pressure, temperature, and gas/liquid flow rate	111 KSC 185˚C 2.3 MMSCMD
Actual hydrostatic test pressure of the line	166.5 KSC
Configuration of the line at the location of leak	After the elbow to Pipe joint , between 6-9 O'clock position
Details of corrosion protection measures including inhibitor and bactericide dosing:	GCI injection at compressor gas inlet manifold

2.0 LABORATORY INVESTIGATIONS

2.1 VISUAL INSPECTION:

Failed PGC Cooler Outlet line samples were visually inspected and the observations were made.

2.2 ELEMENTAL COMPOSITION ANALYSIS:

Chemical compositional analysis was carried out on the PGC cooler piping by spark spectrometric analysis as per test method ASTM[1] – E-415-08.

2.3 TENSILE TESTING:

The tensile testing was carried out to evaluate the tensile strength of the PGC cooler piping sample prepared to ASTM A370 specifications. The tensile tests included determination of yield strength, ultimate tensile strength and percentage elongation and were performed with the specimens at room temperature.

2.4 IMPACT TESTING:

To check the fracture toughness of the cooler outlet pipe material, impact testing was carried out as per method ASTM-E 23- 07 a (2009).

2.5 HARDNESS TESTING:

Hardness of PGC cooler outlet line sample was measured on a representative hardness test specimen prepared from transverse section using a Vickers hardness tester. Indentations were made with 3.0 kg load and observed at 400X magnification. Indentations were made across the thickness of the pipe.

2.6 CONDENSED WATER ANALYSIS:

Condensed water received from platform was analyzed for pH, Bicarbonate, Chloride, Salinity as NaCl , Calcium , Magnesium and Sulphate

2.7 METALLOGRAPHIC STUDIES:

PGC cooler outlet lines were subjected to metallographic examination to analyze the microstructure of the components. Specimen were prepared from the transverse section as well as longitudinal section comprising of welded joint. Metallographic sample preparation was done by grinding the samples with emery papers of different grits (through 120 to 800 grit sizes). Thereafter these samples were polished with diamond paste on a polisher to achieve a finish of 1.0μ. The prepared surface was cleaned properly and dried. These specimens were observed under inverted metallurgical microscope (Nikon - EPIPHOT TME).

2.8 SCANNING ELECTRON MICROSCOPIC STUDY:

Failed surface of PGC cooler outlet line was examined under Scanning Electron Microscope Hitachi 3400 N to analyze its morphology and nature of failure. The samples were cleaned in ultrasonic cleaner and dried.

[1] ASTM American Society Testing and Materials

2.9 CORROSION RATE EVALUATION STUDIES

Gravimetric corrosion simulation studies in High Temperature High Pressure (HPHT) Autoclave were carried out on the metal coupon prepared from the PGC-cooler line material sample under simulated operating conditions. Coupons were wet ground to a surface finish of 240 grit and degreased with acetone. Then the area and weight of the coupon were measured. Subsequently, coupon was exposed to the condensed water sample with pH 4.08 under operating conditions of temperature and flow for 24 hrs in HPHT Autoclave. After the test, coupon was successively cleaned with Clark solution (a combination of hydrochloric acid and inhibitors) and water and acetone and then air dried. From the observed weight loss, area of exposure and density of pipeline steel, the corrosion rate was calculated in mpy.

2.10 ENERGY DISPERSIVE SPECTROSCOPY (EDS) ANALYSIS:

Energy Dispersive X-Ray Spectroscopy (EDS), a chemical microanalysis technique was used in conjunction with scanning electron microscopy (SEM) to quantitatively characterize the elemental composition of the samples under analysis. EDS analysis of pitted region was carried out through NSS software.

3.0 TEST RESULTS

3.1VISUAL INSPECTION:

Failure had taken place in the straight portion downstream of welded joint to the elbow. Failure was in the form of thin metal sheet busted out of the pipe at 6 O'clock to 9 O'clock position downstream of extrados of the elbow (Photoplate 1).
Busted portion of the piping bore the sand dune pattern (Photoplate 2) which was aligned along the flow direction.

	
Photoplate 1: Third stage cooler outlet lines of PGC	Photoplate 2: sand dune pattern on the internal surface of the piping.

3.2 ELEMENTAL COMPOSITION ANALYSIS:

The results of Chemical compositional analysis are given in the table 2 below:

TABLE- 2: Chemical composition analysis of PGC cooler piping

% Composition Element	**PGC cooler piping**	**ASTM A106 Grade B[1]**
Carbon	0.06	0.30 max
Silicon	0.22	0.10 min
Manganese	0.91	0.29-1.06-
Phosphorus	0.014	0.035 max
Sulfur	0.002	0.035 max
Nickel	0.10	0.40 max
Chromium	0.12	0.40 max
Molybdenum	0.038	0.15max
Copper	0.11	0.40 max
Vanadium	0.032	0.08 max
Iron	Balance	Balance

The chemical compositional analysis shows that PGC cooler piping material composition is conforming to ASTM A 106 Grade B material.

3.3 TENSILE TESTING:

The tensile testing results are as given in table 3 below:

TABLE 3: Tensile Test Results

Sl. No.	PARAMETER	Test Results	Specified Values as per **ASTM A 106 Grade B**
1	Y.S. N/mm2	326.85	240 min
2	U.T.S. N/mm2	433.32	415 min.
3	% Elongation	38.88	30 min.

The tensile strength of the tested sample complied with the specified value as required by ASTM A 106 specifications for Grade B material.

3.4 IMPACT TESTING:

The average CVN (Charpy V notch) absorbed energy for the test sample was found to be 294 Joules. ASTM A 106 doesn’t specify the impact test values, however CVN value of 294 joule indicates that the material has sufficient fracture toughness.

3.5 HARDNESS TESTING:

The average hardness of the pipe sample measured was 152 HV. For NACE/ISO 15156-2[2] specification complied carbon steel tubular components the maximum specified hardness is 22 HRC (250 HV). Hence, the PGC cooler outlet line comply with the requirement of NACE/ISO 15156-2 specification.

3.6 CONDENSED WATER ANALYSIS:

Analysis of Condensed water received from the offshore platform showed following values for different parameters:

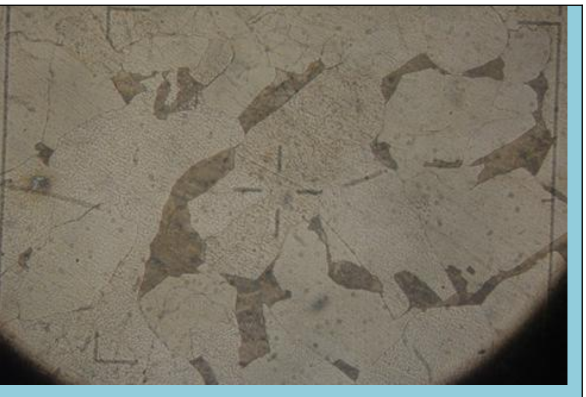
Table 4: Condensed water Test Results

Parameters	pH	Bicarbonate	Chloride	Salinity as NaCl	Calcium	Magnesium	Sulphate
ppm	4.08	61	142	234	20	6	80

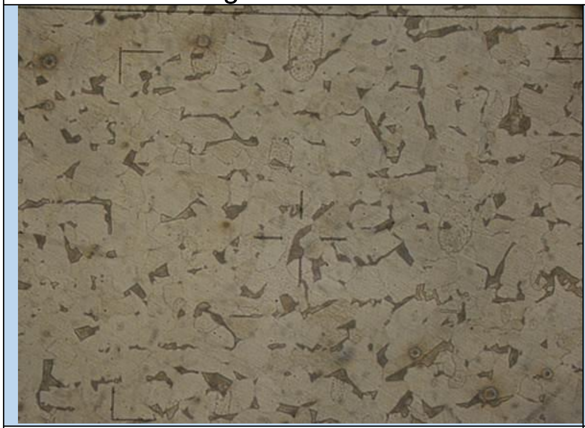
Analysis of the condensed water show that it has a very low pH indicating that it is acidic in nature thus is highly corrosive. However, other ions are not present in significant amount.

3.7 METALLOGRAPHIC STUDIES:

As-polished sample from longitudinal section showed no significant inclusions in it. However, small pits typical of acid attack were observed in it (Photoplate-3) which might have resulted due to exposure to acidic condensate from the gas intercoolers.
The specimens were then etched with 2% Nital. Observation of transverse section revealed a microstructure of uniformly distributed ferrite and pearlite (Photoplate-4). The PGC cooler outlet line had acceptable microstructure of normalized ferrite and pearlite as required by ASTM 106 for Grade 'B' material.
The examination of the etched longitudinal section showed normalized ferrite and pearlite microstructure. In the HAZ, fine grained ferrite and pearlite microstructure was observed (Photoplate-5). Longitudinal section also showed acid attacks at several places (Photoplate-6).



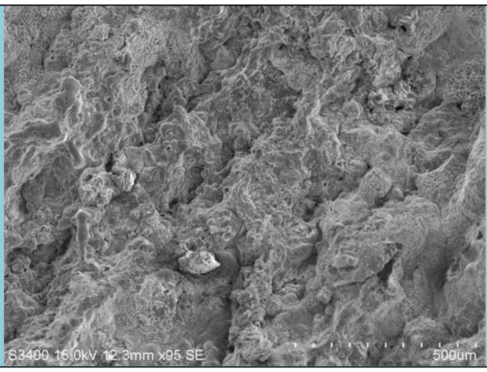
Photoplate 3 : Longitudinal section of the as-polished sample showing pits typical of acid attack. Magnification: 200X.	Photoplate 4: Transverse section showing normalized ferrite and pearlite. Magnification: 400X, Etchant 2% Nital

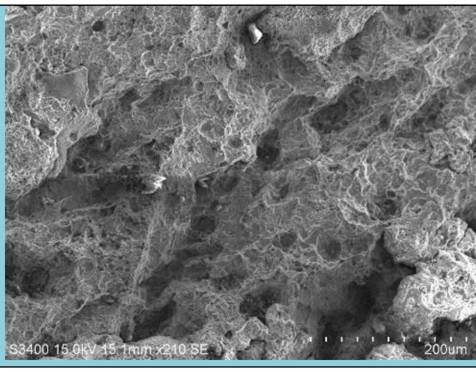


Photoplate 5: Fine grained microstructure observed on the HAZ. Magnification: 200X, Etchant 2% Nital	Photoplate 6: Longitudinal section showing acid attacks at several places. Magnification: 200X, Etchant 2% Nital

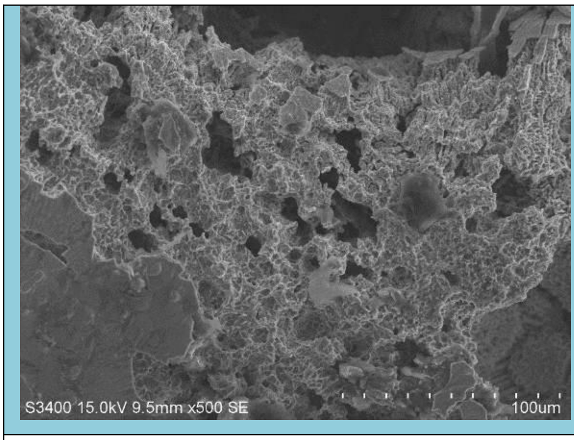
3.8 SCANNING ELECTRON MICROSCOPIC STUDY:

The compressed gas is cooled by passing it through inter coolers which leads to condensation of water. In the cooler outlet lines pressure drop and turbulence is created due to change in cross-sectional area of discharge header of cooler and outlet lines, presence of bends/ elbows in the piping. This causes erosion corrosion of the piping material by rapidly moving fluid (gas, condensate and water) from the gas cooler. In the failed sample, depressions were formed at the initiation sites, which were aligned to the direction of fluid flow (Photoplate 7& 8). These grooves are typical evidence of erosion corrosion mechanism. Closer examination of these grooves showed small pits on it that indicate the influence of corrosive condensed water which aided in erosion corrosion of piping (Photoplate 9). Observation of pits on higher magnification showed the morphology typical of chloride attack on the metal surface (Photoplate 10). Through EDS analysis it was confirmed that the region of this morphology predominantly contained chlorides. In many pits this morphology was observed.





Photoplate 7& 8: Grooves typical of erosion corrosion observed on the failed piping sample

	
Photoplate 9: Pits observed on the grooved region showing influence of corrosive condensed water.	Photoplate 10: Observation of pits at higher magnification showing the morphology of chloride attack.

3.9 CORROSION RATE EVALUATION STUDIES

Corrosion rate evaluated from the observed weight loss in the exposed coupons , area of exposure and density of pipeline steel is given in the Table below

TABLE-5 : Corrosion rate of PGC-cooler line material under simulated condition

	PGC-cooler line	Exposure media	Corrosion Rate mpy (mm/yr)
1.	Coupon fabricated from failed sample	**condensed water** Temperature 56 deg C Operating Pressure 1278 psi pCO_2 43 psi Duration 24 hrs	51.774 mpy (1.314 mm/yr)

The HTHP simulation study shows significantly high corrosion rate of 1.314mm/yr. In this corrosive environment the existing metallurgy is susceptible to even higher corrosion under the condition of erosion corrosion.

3.10 ENERGY DISPERSIVE SPECTROSCOPY (EDS) ANALYSIS:

Analysis of pits on the failed portion of PGC cooler outlet line showed predominantly Fe, oxide, Cl and Ca. Significant amount of chloride in the pits indicate its influence in the corrosion process. Elements analyzed are given in Table- 7 and location of scan in Photo plate 21.

	**Table 6: EDS analysis of pitted region in failed piping sample**

	Elements Wt % /Location	O	Mg	S	Cl	Ca	Fe
	MNP-PGC cooler line	39.43	0.00	0.00	3.82	0.02	56.73

4.0 DISCUSSION

The severity of the sour environment for condensed water of PGC was determined in accordance with NACE/ISO 15156-2 .In the present case In-situ pH determined from calculated partial pressures of CO_2 and H_2S are as under. To calculate in situ pH of condensed water using nomogram given in NACE/ISO 15156, summation of pCO2 and pH2S is utilized. In situ pH and SSC regions at different stages of compression were calculated with the help of NACE/ISO 15156.

Table 7: Evaluated SSC severity regions

	System pressure-Kg/cm2	CO_2 %,	CO_2 partial pressure-Kg/cm2	H_2S-ppm,	H_2S partial pressure-Kg/cm2	In situ pH-	SSC region
1st stage compression	35	3.26	1.141	90	0.0031	4.1	0
2nd stage compression	55	3.26	1.793	90	0.0049	3.92	0
3rd stage compression	92	3.26	3	90	0.0082	3.9	2

It was observed that at the 3rd stage compression, as the system pressure rises the SSC region of environmental severity changes from SSC region 0 to SSC region 2 with the same amount of H_2S and CO_2 (CO2 used for the in-situ pH calculation). However, the hardness test results showed that ASTM A 106 grade B material of PGC cooler outlet line was NACE/ISO 15156-2 compliant and it was resistant to SSC.

High pressure drop after the gas cooler outlet header significantly increase the velocity of the flowing fluid in the outlet lines. As aggressive substances, such as carbon dioxide, and hydrogen sulfide, chloride are present, higher velocities increase the supply rate of the substance to the metal surface, thereby increasing the corrosion rate. Higher gas velocities above 15 m/s may not allow the inhibitors to form protective film over the metal surface. Even though the gas velocities were not calculated, the morphology of the failure (shown flow assissted corrosion like striations), the high corrosion severity observed in the surface and the fact of the failure in itself, seems to suggest that the corrosion inhibitor was not working. Hence the use of existing metallurgy of ASTM A 106 Grade B material along with corrosion inhibitor may not suitable under the high velocity corrosive fluid flow condition in PGC cooler outlet line.

Literature on Material Selection and Corrosion Control for Topside Process and Utility Piping and Equipment[3] suggests that in Gas Compression and Dehydration System typical CRA material used for piping are 316/316L dual grade and duplex stainless steel. Environment limit for 316/316L dual grade piping is Temperature: 60 Deg C, pH2S: Any, Chloride: any, pH: any.

5.0 CONCLUSION AND RECOMMENDATIONS

The chemical compositional analysis, tensile strength and hardness value of the tested sample were found to be complying with the specified value as required by NACE/ISO 15156-2 compliant SSC resistant ASTM A 106 Grade B material. The piping had an acceptable microstructure of normalized ferrite and pearlite.

PGC cooler outlet after 3rd stage have a pressure of 92 Kg/cm^2 and it has 3.26% CO_2, 90 ppm H_2S along with condensate. All the corrosion studies have shown that existing metallurgy of piping is susceptible to CO_2 corrosion. In metallographic studies, small pits typical of acid attack were observed at several places. This attack might have resulted due to exposure of the piping to acidic condensed water from the gas intercoolers.

Visual inspection of the failed surface showed the classic sand dune like surface contours oriented along the direction of fluid flow which is typical of Flow Assisted Corrosion (FAC)

FAC of PGC cooler outlet line took place due to high velocities and turbulence of the fluid caused by abrupt change in cross sectional area of cooler outlet header and outlet lines, elbows present on the piping.

In SEM analysis also grooves typical of erosion-corrosion mechanism were observed. Closer examination of these grooves showed small pits on it that indicated the influence of corrosive condensed water.

EDS analysis of pitted region on failed piping surface confirmed the influence of corrosive species like chloride.

Localized metal loss of cooler outlet piping continued under the influence of erosion-corrosion to a critical thickness and beyond which it could not withstand the working pressure and failed abruptly.

As the existing metallurgy of ASTM A 106 Grade B material along with corrosion inhibitor may not suitable under the high velocity corrosive fluid flow condition in PGC cooler outlet line, it was recommended to use 316/316L dual grade CRA material piping.

6.0 ACKNOWLEDGEMENT:

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