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An Examination of Surface Morphology and In-Situ Study on ASTM A106-Gr.B 'CUI' Piping in EDC Plant

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ABSTRACT
Corrosion under Insulation (CUI) is one form of degradation on process piping and pressure vessels that occurs underneath insulation as a result of condensed steam that has been trapped in to the insulation due to the temperature dissimilarity between the barriers. The water may come from seasonal, leakage through overheads, deluge system, wash water, or sweating from temperature cycling or low temperature operation such as refrigeration units. Unfortunately, because the corrosion is hidden under the insulation, CUI tends to remain undetected until the insulation is removed for inspection or when leak occurs. CUI is a common and also severe problem across many industries including refinery, petrochemical, fertilizer and power plant, onshore & offshore industries. The root cause of CUI is very simple that the interface between the pipe insulation and the substrate to which the insulation is applied there is a temperature differential. Regardless of how tight a pipe insulation material is wrapped around, or applied to, the substrate there is a space where the temperature makes a quick change from higher to lower and that causes a release of moisture and sweating commonly referred to as condensation which leads for the cause of superficial rust formation. CUI is in the form of localized wall loss on carbon steel and 300 series stainless steel. On carbon steel, it's evident as localized thickness loss. With the stainless pipes, it is often pitting corrosion and induced stress corrosion cracking (ISCC). Proper wrapping of insulation and providing barricading novel surfactant through Cathodic Protection (CP) are the main sources to control CUI failures.
Keywords: CUI, EDC, ISCC, CP, OSHA, LDP, HVP, TI & PI, SCC, CR, RBI, DM and PMI.

I. SYSTEMS SUSCEPTIBLE TO CUI:

The American Petroleum Institute inspection code such as API 510 & 570 for repair, alteration and rerating of in-service process piping systems that have become an industry standard to regulate its activities. Damage mechanism is mandatory for CUI and its mitigation guided by the code. Occupational Safety and Health Administration (OSHA) 1910 is the rule with the teeth for personal safety.

I.1. Susceptible areas for CUI:

- Areas exposed to mist overspray from cooling water towers.
- Areas subject to process spills, ingress of moisture, or acid vapors.
- Areas exposed to deluge systems.
- Areas exposed to steam vents.
- Carbon steel piping systems, including those insulated for personnel protection, operating between 10°F and 350°F. CUI is particularly aggressive where operating temperatures cause frequent condensation and re-evaporation of atmospheric moisture.
- Stain less steel (Austenitic) piping systems, including those insulated for personnel protection, operating between 140°Fand 350°F.
- Duplex steel piping systems, including those insulated for personnel protection, operating between 280°F and 350°F.
- Dead legs and attachments that protrude from insulated piping and operate at a temperature different than the active line.
- Vibrating piping systems that have a tendency to inflict damage to insulation jacket and providing a path for water ingress.
- Piping systems that have been deteriorated due to peeled off paints or coating and or productive wrapping.
- Steam traced piping systems that may experience tracing leaks, especially at the tube fittings beneath the insulation.
- Low Drain Points (LDP) and High Vent points (HVP) are critical locations for CUI.
- 45^o, 90^o and 180^o elbow locations also suspected to easy attack of CUI.
- All attachments and structural support locations in the vessel suspected for CUI.
- Insulated equipment's Man way & its cover and

the vicinity area locations are suspected for CUI.

- ❖ Locations where insulation plug have been removed to permit UT thickness measurements on insulated piping should receive particular attentions.
- ❖ Temperature Instrument (TI) & Pressure Instrument (PI) insulated locations on the process piping are predictable for mild to moderate surface CUI.

I. 2. Background:

Corrosion occurs in the presence of moisture. For example when iron is exposed to moist air, it reacts with oxygen to form rust,

$$Fe_2O_3 - H_2O$$

The amount of water complexes with the iron (III) oxide (ferric oxide) varies as indicated by also determines the color of rust, which may vary from black to yellow to orange brown. The formation of rust is a very complex process which is thought to begin with the oxidation of iron to ferrous (iron "+2") ions.

$$Fe \longrightarrow Fe^{+2} + 2e^-$$

Both water and oxygen are required for the next sequence of reactions. The iron (+2) ions are further oxidized to form ferric ions (iron "+3") ions.

$$Fe^{+2} \longrightarrow Fe^{+3} + 1e^-$$

The electrons provided from both oxidation steps are used to reduce oxygen as shown.

$$O_2\,(g) + 2H_2O + 4e^- \longrightarrow 4\,OH^-$$

The ferric ions then combine with oxygen to form ferric oxide [iron (III) oxide] which is then hydrated with varying amounts of water. The overall equation for the rust formation may be written as:

$$4Fe^{+2}(aq) + O_2\,(g) + \{4+2X\,H_2O\,(l)\} \longrightarrow \underset{\text{"Rust"}}{Fe_2O_3}$$

The formation of rust can occur at some distance away from the actual pitting or erosion of iron as illustrated below. This is possible because the electrons produced via the initial oxidation of iron can be conducted through the metal and the iron ions can diffuse through the water layer to another point on the metal surface where oxygen is available.

This process results in an electrochemical cell in which iron serves as the anode, oxygen gas as the cathode, and the aqueous solution of ions serving as a "salt bridge" as shown below.

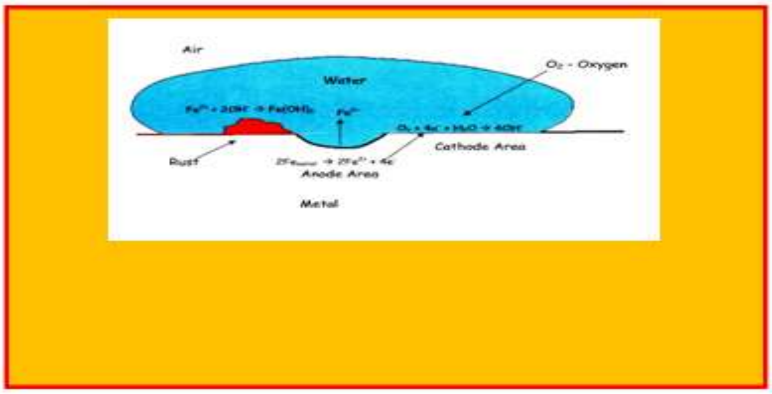

Fig – 1

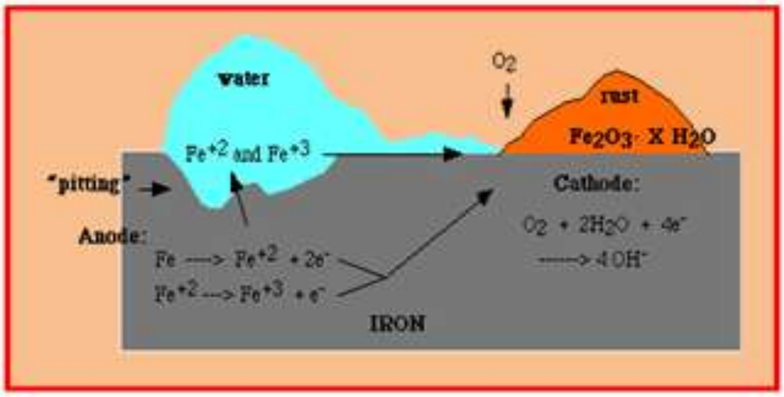

Fig – 2

I. 3 Affected materials:
Carbon steel, Low alloy steel, 300 & 400 Series SS and Duplex SS

II. 1. Mechanism of CUI:

- Availability of oxygen
- High temperature
- Concentration of dissolved species
- Environmental corrosive scale
- Stagnation of moisture on the barrier

3.1.1Availability of oxygen: a poultice effect is created which holds in the moisture which essentially makes its closed system due to condensation. Hence CR is accountable for RBI assessment. Moisture in many forms can entrap in an insulation systems. Rainwater and flooding from deluge systems are accountable. The next source of moisture is water vapor penetrating and soaking down the insulation systems operating at or below ambient temperatures. Corrosion rates are dramatically reduced below 10^{O}F.

3.1.2High temperature: Operating temperature is the next most important element. Above 350^{O}F, most moisture CDA algorithm presented in the following Figure considers distance to salt water, leading either to the very severe AA rating for close distance to seashore or a consideration of moisture factors. However, between 10^{O}F and 350^{O}F is where CUI can happen for carbon steel, and between 140^{O}F and 350^{O}F for 300 series stainless steel. The "optimum" temperature range for aggressive corrosion on both carbon steel and 300 series stainless steel is between 200^{O}F and 350^{O}F. In this range, there is plenty of heat energy but not enough of heat to efficiently evaporate moisture before it contacts the equipment surface.

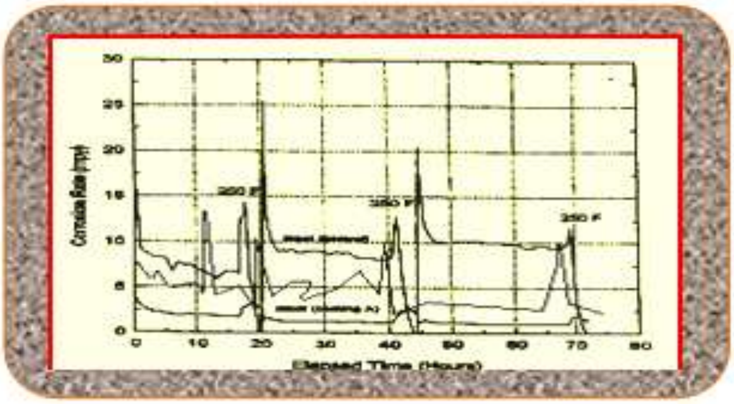

Fig – 3

2.1.3Concentration of dissolved Species: In some cases, chlorides are present in the insulation which greatly promotes corrosion of the underlying surface which it becomes laden with moisture. To have an anticipation of SCC on 300 series stainless steel is due to the penetration of chloride ions. Obviously, oxygen is abundant and readily available. But maybe surprisingly, so too are chloride ions, which can be found in a widely in variety of places from seawater, drinking and process water, and chloride chemical compounds to roadway de-icing salts. The presence of acids, acid gases, strong bases and salts can also create and accelerate corrosion.

2.1.4. Environmental corrosive scale: Based on atmospheric parameters, a corrosion damage algorithm (CDA) was proposed as a guide for anticipating the extent of corrosion damage and planning maintenance operations. This classification scheme was developed primarily for uncoated aluminum, steel, titanium and magnesium alloys exposed to the external atmosphere at ground level.
Five main associated drives necessary for CUI.

- Insulation selection,
- Equipment design,
- Protective Paints and Coatings,
- Weather barriers; and
- Maintenance practices.

In some cases, chlorides are present in the insulation which greatly promotes corrosion of the underlying surface which it becomes laden with moisture due to precipitation as a result pitting and general thinning occur in CS at surface level and SCC occurs in 300 series SS and therefore the leak will develop.

2.1.5Stagnation of moisture on the barrier: Based on atmospheric moisture, the entrapment may lead to stagnation on the barrier surface at particular location will develop CUI. Hence, condition monitoring through external visual inspection should be frequently conducted. If any appearance of stain marking externally on the insulation cladding material, that location should be inspected by providing window opening.

3.1Methods of Inspection:

Inspection for CUI should be concentrated on those areas where water can pass through insulation covering and where it would collect after it passes through. CUI inspected through 100% visual inspection on class 1 & 2 and 50 % of all class 3 piping. It is a good practice to prioritize those locations where CUI has the strongest potential. NDE methods such as profile Radiographic test (PRT) up to 2" nominal pipe size (NPS). There are a number of methods also used to inspect for CUI like Ultrasonic Thickness (UT) readings, real-time X-ray. Real-time X-ray has proven to be a safe, fast and effective method of inspecting pipe in plant operations.

3.2Case History:

In the cracking unit, a line which was 12 years in service got cracked gas from the caustic treating section is dried in the process cracking furnace to prevent freezing in the downstream cold section of the plant. The wet process gas is dried so that it will contain less than 0.1ppm water when it flows to the cracked quench column. 14"adiabatic line is made of carbon steel SA 106 Gr.70 with cellular glass insulation. The design conditions are 4300 kPa at 0^oC to 219^oC and 3700 kPa at 340^oC. The quenched feed is at 15.6^oC design (12.5^oC in existing operation) and 3548 kPa with a molecular weight of 18.9. When the quenched tower spends 130 hrs in service or the percentage weight of water content reaches about 5 ppm, the tower will be isolated, regenerated, and purged. Then, tail gas (T. G.) heated to about 230^oC is introduced into cracking furnace. A leak was observed during the unit start up on a 4" start up line coming from 14" adiabatic line. This leak was located at the top platform of the wet EDC tower. Visual inspection revealed damaged insulation with CUI. The depth of the CUI appeared to be very significant, down to paper thin at the vicinity leaky area while the nominal thickness was 10.0 mm as shown in Fig – 4. The 4" line was sometimes used as a step by persons on the plat form, which may cause bend

ing stress. This stress could be one of the contributing causes to the final failure of the pipe.

Fig – 4

The leaky line was insulated by Cellular Glass, and coated by Inorganic Zinc. Moreover, numbers of probable root causes were found as follows:

- ❖ The line subjected to cyclic temperature. As mentioned above, there was tail gas introduced into the dryer at two different temperatures 230^0C and 65^0C other than the normal process gas temperature 12.5^0C. This means that there was a cyclic temperature (12.5^0C to 230^0C).
- ❖ Due to cyclic temperature, moisture was generated under the thermal insulation and on the line surface. This moisture worked as a media connecting the anodic areas to the cathodic areas. As a result, corrosion under thermal insulation (CUTI) started.
- ❖ No enough CUI awareness

3.3Recommendations:

- ❖ Punctured portion of pipe up to acquire the nominal thickness was recommended to replace.
- ❖ Proper coating system was recommended for cyclic temperature.
- ❖ All insulation shall be removed and recommended for RBI assessment and identify all susceptible CUI areas.
- ❖ Add all CUI lines in the piping monitoring program (RBI).
- ❖ Strip out the insulation when NDE result shows any problems.
- ❖ Prepare a plan to inspect all susceptible CUI lines, and
- ❖ Increase the awareness among the Inspectors & Operation personals.

3.4PMI Examination:

Positive Material Identification (PMI) inspection was conducted on CUI affected area, after completion power tool cleaning which revealed the composition of ASTM A 106 Gr. B process piping line that have been exhibited degradation swiftly. (Table – 1)

ASTM A 106 Gr. B	C	Si	Mn	P
	0.30	0.10	0.29 – 1.06	0.035
	S	Cr	Mo	Ni
	0.035	0.04	0.15	0.42

3.5Metallography:

After removal of insulation from the carbon and low alloy steel, CUI damage often appears as loose, flaky scale covering the corroded ASTM A 106 Gr. B piping. Damage was seemed to be highly localized as shown in Fig -5 and associated with carbuncle type pitting.

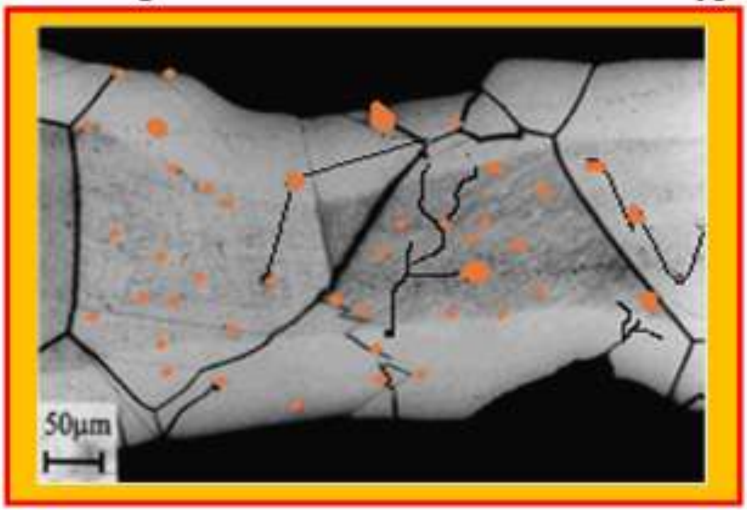

Fig – 5

For 300/400 series SS, specifically Stress Corrosion Cracking (SCC) that had seen at the removed window insulation where suspected as shown in Fig -6. Subsequently removal of the flaky superficial corrosion, the affected area was stringently cleaned with 2 ½ Grid blast and inspected by means of In-situ metallographic which exhibits the initiation of SCC at the root of clustered pitted area due to CUI.

Fig – 6

3.5Inspection Procedure for CS:

- Clean off surface rust and corrosion product by high pressure water jetting or wet abrasive blast.
- Locate and mark corrosion and pitting in Isometric.
- Measure remaining wall thickness
- Record the result if the insulation is in place and corrosion areas were found by thermal image scanning, then windows is required to measure the wall loss.

3.6Inspection Procedure for SS:

- Visually inspect for evidence of external stress corrosion cracking
- Clean surface area with high pressure DM water
- Use liquid dye Penetrant around all nozzles and welded attachments and confirming with UT gauging.

If the insulation is in place, use thermal scanning or neutron backscatter (NBS) to identify the suspected areas. By acoustic emission (AE), locate the presence of stress corrosion cracking (SCC). Then cut windows in the insulation to repair the affected areas.

4.1 Conclusion:

We conclude that the moisture is the main responsible factor which develops CUI. Therefore, keeping the insulation dry is a most important step to avoid this problem. Based on the discussed case history, it is important to have well documented inspection program for all piping and equipment including CUI. As we can see that CUI failure's trend is increasing, this indicates the need for such program.

Recommendations to minimize CUI failure:

1. Establish piping and equipment inspection program and include CUI inspection.
2. Inspect class 1 and 2 equipment and piping system as per API 570 and API 510 recommendations as a minimum to avoid major loss in the plant when failure occurred.
3. Maintain the insulation outside jacketing condition by having an effective preventive maintenance (PM) and quick repair program in order to prevent water getting in the insulation.
4. Use proper protective coating system.
5. Provide awareness sessions to operation, maintenance and field people on the CUI and the importance of keeping the outside jacketing intact with no damage.
6. Where opened insulation windows shall be sealed with insulation plug and Condition Monitoring Location (CML) identification marked on the Isometric as well as on the G.A drawing for future reference and inspection.
7.
8. Design temperature of the process line and equipments should be reviewed and recorded.
9. According to the temperature of the piping proper surface coating shall be applied subsequently wrapping of aluminum foil sheet shall be also wrapped over the piping to avoid entrapped water or moisture in to the insulation.
10. Insulation thickness is one of the factors to mitigate the CUI, hence proper thickness of insulation shall be maintained according to the design temperature not base on the operating temperature.
11. No provision shall be allowed to entrapped moisture or water or differential temperature through the left out end of valve's flanges hence, an aluminum foil of wrapper sheet over the insulation material at least on critical locations shall be provided.

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