

Localized Corrosion Management for Thermally Insulated Systems via Insulation Stand-offs and Low Point Drains

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ABSTRACT

CUI (corrosion under insulation) is a major damage mechanism affecting the integrity of process equipment, piping, and pipelines. CUI is known to create localized corrosion and pitting under thermal insulations which trigger non-linear corrosion rates and end up in unanticipated leaks in industrial assets. Reportedly, detection and management of CUI-driven damages constitute 10% of the maintenance budget in a typical refinery. This study simulates the CUI behavior of carbon steel under fibrous stone wool insulation using four testing conditions namely Isothermal wet, isothermal wet-dry, cyclic wet, and cyclic wet-dry. The weight loss of coupons under each test condition was converted into corrosion rate followed by characterization of damage modes namely pitting, uniform corrosion via microscope, and surface topography. It also compares the corrosion behaviors in closed-contacting insulation to those produced under contact-free insulation with low-point drains under similar testing conditions. Unlike closed-contacting insulations, coupons under contact-free insulation with low-point drainage resulted in uniform corrosion, insignificant pitting, and reduced corrosion rates under all testing conditions.

Key words: Insulation, corrosion under insulation, localized corrosion, uniform corrosion, corrosion mechanisms, optical microscopy, thermal cycling

INTRODUCTION

Corrosion under thermal insulations namely CUI (Corrosion under insulation) is a key degradation process in hydrocarbon facilities which poses asset integrity risks. ¹ CUI is reported as the reason

behind 40-60% of failures of the process piping in a typical oil refining facility. Speaking smaller-sized process piping (i.e., NPS < 4"), up to 81% of reported failures are known to result from CUI.² Monetary spending to inspect and fix CUI-related failures cost 10% of overall maintenance budget in a typical medium-sized oil refinery.² CUI risk is influenced by numerous operational and environmental factors which impedes its management in a typical AIM (Asset integrity management) program. The key driving factor behind CUI is the aerated moisture on the metals that comes from soaked thermal insulations.³ The type and condition of insulation materials have significant impact on their moisture absorption tendency and subsequent CUI rate(s). Other than triggering CUI, the absorbed moisture degrades thermal insulative ability of insulation via increasing the thermal conductance. Reportedly, 5% moisture content within stone wool insulation increases the thermal conductance up to 25%.⁴

Various known measures for CUI management used today are protective-coatings, material upgrades to corrosion-resistant alloys, use of water-repellent (i.e., hydrophobic) insulations etc. Materials upgrades require significant capital investment can become unviable due to environmental conditions as well e.g., austenitic stainless steels are prone to Cl⁻ stress corrosion cracking in marine and high chloride environments. Although water repellent insulations resist moisture intrusion due to their hydrophobic nature, the hydrophobicity of such insulations can be compromised under immersion conditions, a condition which can likely happen at a low point (i.e., 6'o'clock) in the event of moisture trapping between jacketing and insulation.⁵ Although protective coatings offer surface protection under thermal insulations, their long-term performance gets compromised especially when subjected to thermal cycling in oxygen-starved moist conditions under soaked thermal insulations, which in turn causes partial detachment of coating and even holidays via full-delamination. Previous study by Yang et. al., has reported the failure of conventional phenolic epoxy coating under CUI simulation conditions.⁶

Recommended practices suggest drainage of trapped moisture via low point drains (alongside 6'o'clock) to reduce the time of wetness and consequentially reduce CUI risk(s) in thermally insulated systems.⁷ A previous study by Rana et. al. addresses the influence of low point drains and insulation stand-offs on moisture removal behavior of fibrous stone wool insulation.⁸ Insulation stand-offs help to keep the insulation off the pipe which reduces the probability of moisture trapping that may otherwise result in permanent attachment of moisture to the metal's surface via surface tension and capillary action. Previous studies have reported the influence of insulation stand-offs and low point drains on CUI performance of uncoated carbon steel.⁹⁻¹⁰ CUI rates of carbon steel were found substantially lower in the presence of contact-free insulation and low point drains.⁹

Since industry standard for insulation manufacturing allows significant tolerance (up to 25%) in the thickness of finished stone wool insulation, the drilling through the unknown thickness of stone wool insulation is impractical as it poses the risk of pipe damage from the powered drill's impact.⁹ Another challenge towards low point drains is the lower compressive strength of stone wool insulations, which makes existing drain holes (in these insulations) prone to deformation from any loading as well as clogging from corrosion products, respectively. Furthermore, there are various factors such as thermal expansions, mechanical loadings, pipe vibrations, and jacketing deformations due to human/ animal traffic, etc. that can mis-align the opening in the jacketing from the opening in thermal insulation, and in turn, impede the drainage of trapped moisture. Considering the abovesaid maintenance challenges, the design of the low point drains should be improved to ensure the longevity and geometrical integrity of the low point drain openings. This study addresses the quantified impact of drain opening and contact-free insulation systems on the CUI under four different testing conditions namely IW (Isothermal Wet), IWD (Isothermal Wet-Dry), CW (Cyclic Wet), and CWD (Cyclic Wet-Dry) suggested by the applicable ASTM standard.¹¹ This study adds to the previous study by Rana et. al. by conducting detailed surface analyses via confocal laser scanning and surface topography. This study also introduces the schematic model for CUI damage of both contacting and contact-free insulation systems. The corroded specimens were examined for

corrosion rates followed by surface characterizations via confocal laser microscope, surface topography, and SEM (scanning electron microscope).

EXPERIMENTAL WORKS

Carbon steel A106 Gr. B (UNS K03006) coupons were cut (width 2") from a pipe with 3" NPS (nominal pipe size). The coupons were polished to Grit 600 finish over the external surface followed by rinsing with de-ionized water and acetone to clean off any debris from the surface of coupons. The coupons were weighed precisely using a weigh scale with an accuracy of 0.01 gm. The coupons were then installed in CUI test cell over an oil filled barrel with heating element as per arrangement shown in Figure 1. The test coupons were separated from each other by spacing rings and were wrapped with fibrous stone wool insulation and Aluminum jacketing. Figure 2 (a) through 2 (c) shows the cross-sectional views of candidate configurations/ insulation designs that were applied to the coupons in the test cells namely contacting with offset drain hole, closed-contacting, contact-free insulation with low-point drain, respectively. Referring Figure 2 (a), a 6 mm hole in the jacketing was kept slightly offset from the hole in the insulation (instead of a through-hole) to simulate the condition of drain hole/ openings in the jacketing in the event of vibrations or thermal expansions in the insulated pipe(s). For configuration shown in Figure 2 (c), a robust low point drain (i.e., drain plug) was installed at 6'o'clock position, whereas spacers were installed on the inner circumference of insulation to create a stand-off between insulation and coupons. Drain plug and insulation spacers in Figure 2 (c) were supplied by Integrity Products and Supplies Inc.

Electrolyte with pH=6 was prepared by mixing de-ionized water (type IV) with 100 ppm NaCl in line with applicable standard.¹¹ The electrolyte was introduced in the test cell via funnel through 12'o'clock position as shown in Figure 1. Test cell's temperature was maintained using the heated oil inside the barrel via thermocouples and temperature controller. Each candidate configuration shown in Figure 2 (a) through 2 (c) was characterized under various test conditions namely IW, IWD, CW, and CWD as summarized in Table 1. For the isothermal conditions (i.e., IW & IWD), the testing duration was three days (or 72 hours), whereas cyclic temperature tests (i.e., CW & CWD) were conducted for four days (or 96 hours). After completion of the CUI test(s), the insulation was stripped off followed by visual examinations of coupons. The corroded coupons were washed to remove the loose scale and corrosion products. Coupons were characterized by weight loss measurements and surface examinations. Corrosion rates were calculated by incorporating the average weight loss (gm) of three coupons in the below equation (1):¹¹

$$CR = \frac{K \times M}{A \times T \times D} \quad (1)$$

Whereas K = constant i.e., 8.76×10^4

M = weight loss (gm)

A = area of exposure (55.9 cm^2)

T = time of exposure (hours)

D = density of carbon steel coupon (7.87 g/cm^3)

Table – 1: Test conditions for CUI simulation tests

TEST CONDITION	TEMPERATURE				WET-DRY CYCLE DURATION/ 24 Hrs	
	DAY 1	DAY 2	DAY 3	DAY 4	WET CYCLE	DRY CYCLE
IW – Isothermal wet	100 °C	100 °C	100 °C	-	24	0
CW – Cyclic wet	100 °C	40 °C	100 °C	40 °C	24	0
IWD - Isothermal wet-dry	100 °C	100 °C	100 °C	-	20	4
CWD – Cyclic wet-dry	100 °C	40 °C	100 °C	40 °C	20	4

After weight loss measurements, the coupon surfaces were examined via visual and microscopic checks using optical microscope and confocal laser (Keyence VK X-1000). The laser scanning was conducted using high magnification scanning followed by stitching to generate 2D and 3D topographic images, to account for surface features and defects (pits, uniform corrosion, etc.) over larger area (4 mm x 4 mm) with better representation of entire sample. Also, the cross-sections were produced from the corroded coupons using high precision cutting employing CBN (cubic boron nitride) blade. The cross-sections were mounted in conductive mold(s) followed by grinding using SiC grinding paper. Ground-finished cross-sections were polished down to 1 μ m finish using monocrystalline diamond solution. Polished cross-sections were then characterized using SEM to account for morphology and existence of defects (pits, localized corrosion, etc.).

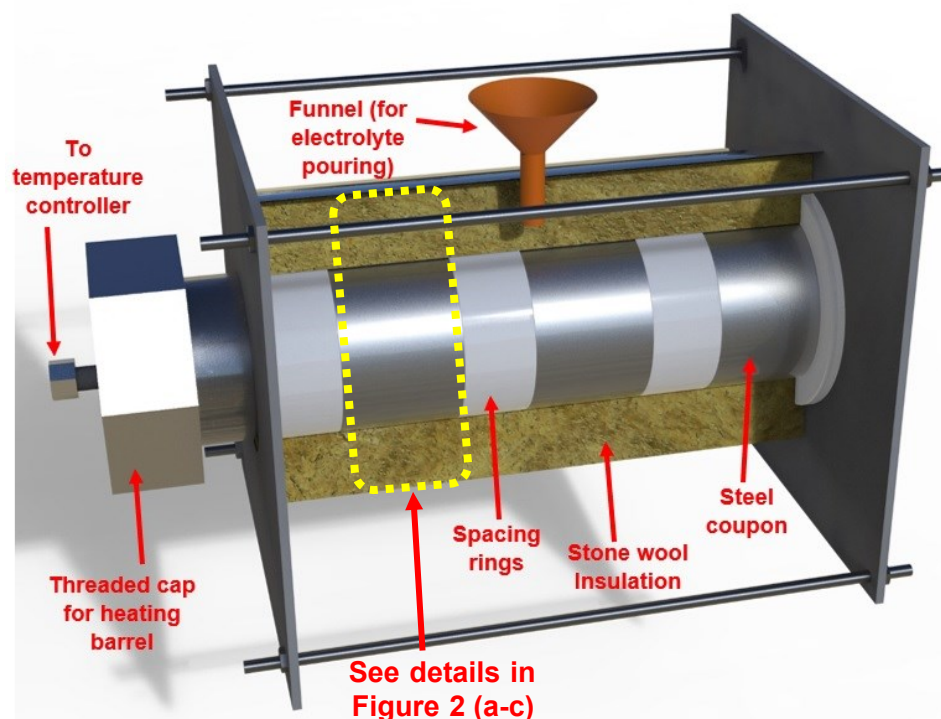


Figure 1 – Arrangement for CUI simulation test

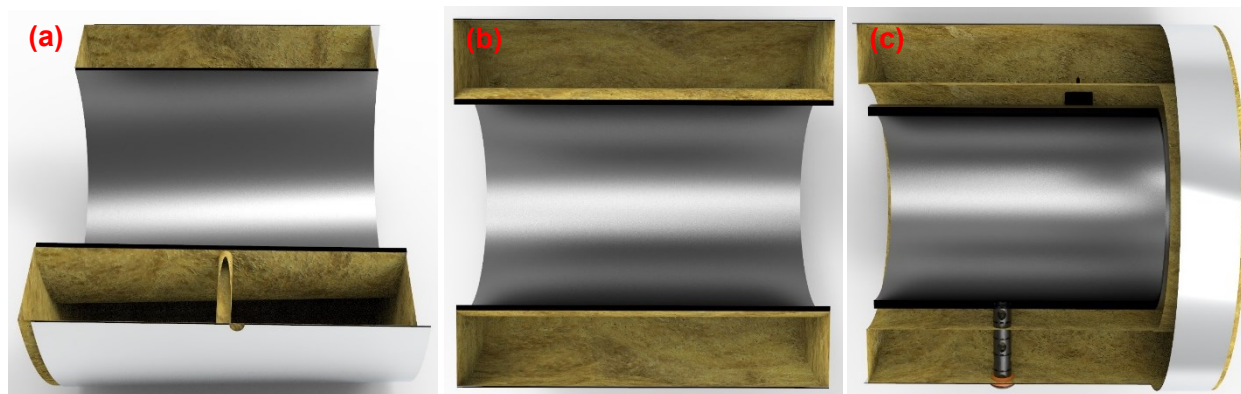


Figure 2 – Candidate configurations (a) contacting insulation with offset drain hole (b) Closed-contacting insulation (c) Contact-free insulation with robust drain

RESULTS & DISCUSSION

Figure 3 summarizes the corrosion rate of carbon steel coupons for each candidate configurations under all testing conditions namely IW, IWD, CW and CWD, respectively. The contact-free insulation system in conjunction with robust low point drain opening has the least corrosion rate among candidate configurations under all testing conditions. Compared with a conventional closed contacting insulation system, contact-free insulation with a robust low point drain opening has lesser corrosion by factors of 1.62 times, 1.5 times, 8.05 times and 2 times under IW, CW, IWD, and CWD conditions, respectively. Whereas the corrosion rates for both contacting insulation systems (i.e., closed-contacting and with offset drain hole) are in proximity as the offset drain hole impedes drainage rate thereby creating the stagnant conditions inside the test cell like those with no drain hole. IWD condition in the systems with contacting insulation caused more corrosion rate than CWD conditions. Figure 4 shows the post-test condition of the coupons before washing of corrosion products.

Referring to Figure 4 (a), dark black scale with some brownish patches is dominant which implies the domination of magnetite scale under a closed contacting insulation. Whereas the contact-free insulation in Figure 4 (b) and 4 (c) reveal the brown scale which can likely be hematite, hydroxides or oxyhydroxides variant (α , β and/or γ). Figure 4 (c) which is for contact-free insulation under cyclic wet conditions shows localized damage from scale detachment. Post-washing micrographs of coupons as acquired from high magnification scanning (over 4 mm x 4mm area) followed by stitching, are shown in Figure 5 (a) through 5 (d). Figure 6 (a) through 6 (c) shows 3D topographies for candidate configurations.