

Corrosion Under Insulation Behavior of Phenolic Epoxy Coatings under Contacting and Contact-free Insulations

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ABSTRACT

CUI (corrosion under insulation) is reportedly a contributor to the failure of insulated piping and process equipment. Protective coatings are among various effective measures to manage the CUI of industrial assets. Phenolic epoxy is among the widely used coatings under thermal insulations. This research work involves CUI testing of phenolic epoxy coating for 192 hours as per applicable ASTM standard G189-07 using cyclic wet operating conditions. The resulting weight loss from the test was converted to corrosion rate followed by microscopic checks. The as-coated (i.e., new) surface and post-test coatings were characterized using microscope and surface topography to account for damage modes and surface roughness. Phenolic epoxy coating under contacting insulation suffered a higher material loss rate, dis-bonding, and holiday defects tendency in comparison to contact-free insulation with low-point drainage.

Key words: Insulation, Corrosion under insulation, Coatings, Phenolic epoxy coating, Degradation, Optical microscopy, Contact-free insulation, low-point drainage

INTRODUCTION

CUI (Corrosion under insulation) refers to localized corrosion under thermal insulations, which pose integrity risks to the hydrocarbon facilities. ¹ CUI is reportedly a driver behind 40-60% of failures in the facility piping. Smaller-sized piping (i.e., diameter < 4") are even more prone to CUI, whereas reportedly 81% of failures in small-sized piping are due to CUI. ² CUI-related failures and associated efforts comprise 10% of a facility's maintenance budget. Management of CUI risks has always been challenging as it involves maneuvering numerous governing factors. The key driving factor behind CUI is the aerated moisture that comes from soaked thermal insulations. ³ The type and condition of insulation materials have a significant impact on their moisture absorption tendency and subsequent CUI rate(s). In addition to triggering CUI, the absorbed moisture deteriorates thermal insulations via increasing the thermal conductance. Reportedly, moisture content of 5% within stone wool insulation causes a 25% increase in thermal loss(es). ⁴

Recommended practice suggests the use of low point drains to release the trapped moisture and reduce the time of wetness for thermally insulated systems. ⁵ A previous study by Rana et al. addresses the influence of low point drains and insulation stand-offs on moisture removal behavior of stone wool insulation. ⁶ Contact-free insulations 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 by Rana et al. and Pojtanabuntoeng et al. have reported the influence of contact-free insulation design and low point drains on the CUI performance of uncoated carbon steel. ⁷⁻⁸ CUI rates of carbon steel were found substantially lower when applied with contact-free insulation, and low point drains. ⁷

Various known measures for CUI management used today are protective coatings, material upgrades to corrosion-resistant alloys, use of water-repellent insulations etc. Materials upgrades require significant capital investment can even be unviable due to environmental conditions, e.g. austenitic stainless steel 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. ⁹

Protective coatings are considered the last line of defense against CUI, so the suitability and longevity of coatings are crucial towards protection against CUI. On the other hand, coating defects (e.g., porosities, holidays etc.) and degradation (full delamination, partial detachment, etc.) can jeopardize the longevity of protective coatings and may even result in localized corrosion. Modern recommended practice suggests the coating adjustment factors and linear degradation rates for coatings for the determination of CUI risks. However, these numbers are qualitative and can pose significant uncertainty in RBI (risk-based inspection) calculations and applicable AIM (Asset Integrity Management) programs. ¹⁰ There has been a reported incident where the falling water from an overhead heat exchanger's cleaning activity triggered CUI on an insulated pipe underneath the heat exchanger, despite the fact the pipe was adequately coated and was already declared of low CUI risk. ¹¹ Hence the quantified CUI behavior of coatings under various insulation designs is not fully understood or reported yet. This study addresses the degradation rates for phenolic epoxy coatings under various designs, namely closed-contacting and contact-free insulations using the applicable standard for laboratory simulation of CUI. ¹²

EXPERIMENTAL WORKS

Ring-shaped test coupons (2" wide) were machined from 3" NPS (nominal pipe size) schedule 40 carbon steel A106 Gr. B (UNS K03006) pipe. Coupons were cleaned via abrasive blasting to achieve

near-white surface (surface profile: Sa 2.5). The prepared coupons were then applied with 02 coats of phenolic epoxy coating via airless spraying method. The coated surfaces were allowed to cure for 10 hours at room temperature. Coupons were weighed precisely using a weigh scale with an accuracy of 0.01 gm. The coupons were then installed in the CUI test cell over an oil-filled barrel with a heating element as per arrangement (cross-sectional view) shown in Figure 1. The test coupons were separated from each other by Teflon rings and were wrapped with fibrous stone wool insulation and Aluminum jacketing. Figure 2 (a) and 2 (b) show the cross-sectional views of candidate configurations of the insulations that were applied to the coupons in the test cells, namely contacting and contact-free insulations, respectively. To achieve the configuration shown in Figure 2(b), a robust low point drain (i.e., drain plug) was installed alongside 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 shown in Figure 2 (b) were supplied by Integrity Products and Supplies Inc.[†] Both test cells had the provision for introducing the electrolyte from 12'o'clock via a funnel. The electrolyte was prepared by mixing deionized water (type IV) with 100 ppm NaCl solution. CUI simulation tests were conducted for 192 hours (i.e., eight days) using the electrolyte under CW (cyclic wet) conditions as per the criteria of the applicable standard (i.e., ASTM G189-07). During the eight days cyclic temperature tests, the temperature was kept at 100°C on odd days and at 40°C during even days, respectively.

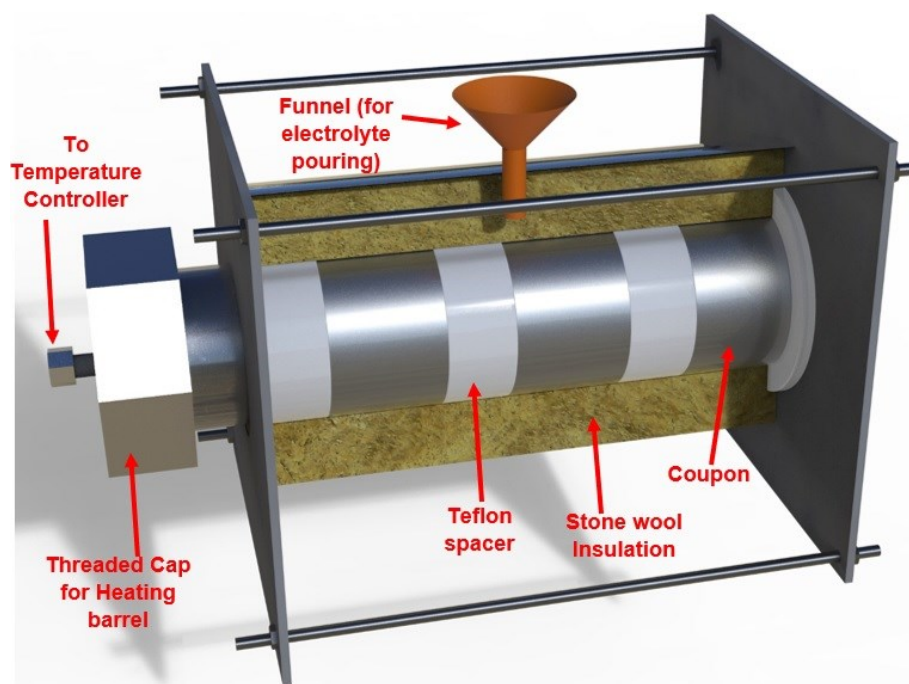


Figure 1 – Arrangement for CUI simulation test

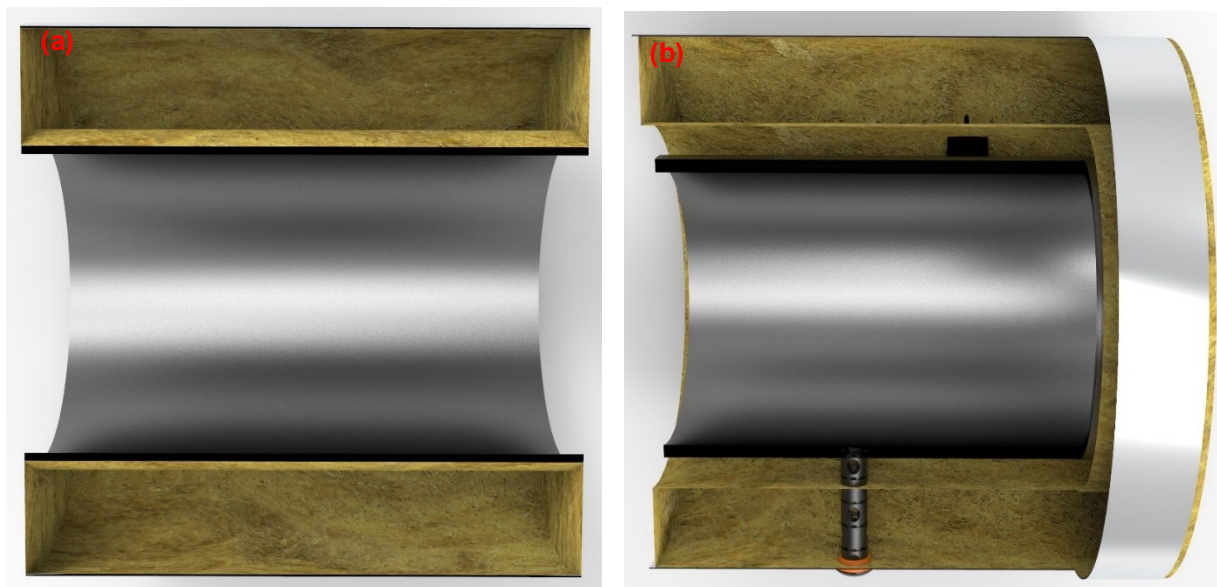


Figure 2 – Candidate Insulation Configurations (a) Closed-contacting Insulation (b) Contact-free Insulation with Drain Plug

After completion of the CUI test(s), the insulation was stripped off, followed by visual examinations of coupons as well as insulation. The corroded coupons were washed to remove the loose scale and corrosion products. Coupons were characterized by weight loss measurements and microscopic examinations. Corrosion rates were calculated by incorporating the average weight loss (gm) of the coated coupons in the below equation (1):¹²

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

Whereas K = constant i.e., 8.76×10^4

M = mass loss (gm)

A = area of exposure (55.9 cm^2)

T = time of exposure (192 hrs)

DFD = Dry film density of coating (g/cm^3)

DFD was calculated via below equation (2) as:¹³

$$DFD = [NV \times D_s \times D_p] \div [100 \times D_s - (100 - NV) \times D_p] \quad (2)$$

NV = %age of non-volatile solids ($68 \pm 2 \%$)¹⁴

D_p = density of the wet paint (1.7 Kg/dm^3)

D_s = density of the solvent (317 g/dm^3) (largest solvent present or often a calculated average of all solvents present)

After weight loss measurements, the coupon surfaces were examined via visual and microscopic checks using the optical microscope and confocal laser (Keyence VK X-1000[†]). The laser scanning