TECHNICAL BULLETIN 0920

Insulant Impact on Corrosion in Steel Piping Applications at Lower Temperatures

PURPOSE

The purpose of this Technical Bulletin is to provide general information on the causes of Corrosion under Insulation (CUI) in steel pipe, to identify which insulants in general terms may be best for low temperature applications, and how to avoid of CUI in steel piping systems operating at "low temperature" environments - - essentially below the temperature of high-pressure steam.

We also discuss how corrosion differs between the two common types of steel[1] used in such piping systems. To keep it simple, we define carbon steel as steel with less than 10.5% chromium, and stainless steel[2] as a steel with a minimum of 10.5% chromium content by weight. There are of course many types and grades of both carbon and stainless steels, with varying degrees of susceptibility to various corrosion processes.

BACKGROUND

Corrosion is defined by the National Association of Corrosion Engineers as "*the deterioration of a material, usually a metal, by reaction with its environment*." CUI is not a distinct form of corrosion; rather it refers to the location where pipe wall material deterioration is occurring - underneath the insulation material and on the external surfaces of piping. CUI (and the corrosion of metal jackets and banding which is not addressed herein) is a recognized problem that must be addressed by designers, specifiers, and end-users. CUI can occur under <u>any</u> type of thermal insulation. The type of corrosion will depend on the metallurgy of the pipe as well as the mix of corrosive elements - - understanding that corrosive elements can be introduced during pipe production, pipe shipping/storage, installation, insulation contact, process liquid contact, weather, or other environmental influences.

Focusing on CUI, the three most common types of CUI include oxidation (rusting), stress corrosion cracking (SCC), and pitting. Yet there are also several specialized types of CUI such as formicary corrosion[3] of copper which in general are not associated with insulated refrigerant systems and therefore not addressed herein. Metals vary considerably in their susceptibility to various types of corrosion.

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[1] We define "Steel" as an alloy that consists mostly of iron and has a carbon content between 0.2% and 2.1% by weight.

[2] Refer to http://www.corrosionist.com/Stainless_Steel_grades.htm.

[3] Formicary ("ants-nest) corrosion may best be described as micro-pitting most common in refrigeration grade copper tubing in HVAC systems although other forms of attack, similar in appearance, have been observed in other alloys. Although poorly understood, attack has been attributed to the growing use of synthetic lubricating oils that were introduced as refrigerant fluids changed, or to vaporous species derived from the immediate surroundings, including volatiles from process fluids.

SUMMARY UP FRONT

Too often, discussions of CUI focus only on the insulation, rather than on the broader spectrum of factors that will more likely be the cause of any CUI. At temperatures below 32°F, the likelihood of any form of CUI is remote. Yet the majority of mechanical systems spend some time above 32°F, such as during outages, so the extent to which an insulant may contribute to CUI must be considered. There are several premises to keep in mind:

1. CUI can in fact occur under any insulant - - some more likely than others
    a. Insulants with higher Water Absorption and Water Vapor Transmission can exacerbate CUI;
    b. Insulants with higher leachable chlorides (or fluorides) can exacerbate CUI (*yet such ions must be leachable at the actual temperature present, and the temperature must be above 32°F!*);
    c. CUI is time and temperature dependent.
2. CUI can be prevented from occurring by following basic guidelines:
    - Pre-design identification of environmental factors that could exacerbate CUI, such as rain, acid rain, humidity, "salt air", wash-down water/chemicals, sprinkler systems, fire control systems, etc.;
    - Pipe/component design using appropriate metallurgy for the conditions, and control of metallurgy during construction (e.g. welding; pickling/heat treating; avoidance of dissimilar metals in contact; etc.);
    - Proper specification and application of any pipe coatings;
    - Proper selection and installation of *insulation system* materials (insulant, vapor barriers, jackets, mastics, etc.);
        - This includes compliance with the guidelines of the manufacturers of the various insulation system components as well as the procedures established by a qualified insulation engineer, including for example, keeping the insulation and pipe surfaces dry during the installation process.
        - Zero-perm vapor barriers can eliminate moisture penetration from the environment.
    - Operational diligence, including such action as avoidance of excessive impingement of water on pipe during wash-downs, periodic inspection for corrosion, and proper replacement of the insulation and insulation components after mechanical repairs or inspection.

Dyplast is not a piping system designer, so cannot provide credible advice on the overall design of a piping system. We thus focus on insulant selection in the next subsection, and on some general information on corrosion in the remainder of the document - - so involved parties may better understand the issues and thus better able to communicate with system designers, engineers, and contractors.

INSULANT SELECTION

Selection of the optimal insulant material is first driven by the long-term thermal performance of the insulant, just as the first priority of the piping is to ensure mechanical integrity of the process. Corrosion mitigation must inevitably be a secondary concern, unless the pipe system is likely to be exposed to a chemically intense environment, such as an acid regeneration plant in a steel mill with frequent leaks. In such an environment, cellular glass may be the only insulant that could withstand the chemical onslaught, assuming the chemicals do not include hydrogen fluoride, hydrofluoric acid, or related compounds.

Polyisocyanurate (particularly Dyplast's ISO-C1) is inevitably the optimal selection in the vast majority of piping applications with operating temperatures below 32°F. The thermal conductivity of ISO-C1 polyiso combined with its moisture resistance characteristics result in energy savings and process control advantages that far outweigh any concern over corrosion.

The additional good news is that ISO-C1 polyiso is low in leachable chloride. At the low temperatures typical of a polyiso installation, CUI is highly unlikely. In systems where there is frequent cycling above 32°F, pipe coatings[4] can further mitigate any risk of CUI.

CORROSION OF STEEL: GENERAL

While dramatically different in nature, the corrosion through oxidation, SCC, and pitting each share one common requirement - - moisture. The corrosion of metals is an electrochemical process. That is, there is an electrical circuit where the exchange of electrons (electricity) is conducted by chemical reactions in part of the circuit. These chemical reactions occur at the surface of the metal exposed to the electrolyte.

Water in the form of liquid or vapor must be present at the surface of the metal for corrosion to occur. Therefore, anything that can be done to prevent moisture (rain, wash-down water, sprinkler systems, condensation, etc.) from reaching the metal surface will help prevent corrosion from occurring. Selecting an insulant with both low water absorption and water vapor transmission, and properly installing a zero-perm vapor barrier with a protective jacket is an appropriate approach in addition to minimizing the external presence of water.

[4] Typical industry practice is to apply an epoxy primer in the following circumstances: 1) for 300 series stainless steel systems operating in a temperature range between 140°F and 300°F or if in a cycling temperature service where the service temperature is between 140° and 300°F for more than 20% of the time; and 2) for carbon steel piping operating at a service temperature between 32°F and 300°F or in cycling temperature service where the service temperature is between 32°F and 300°F for more than 20% of the time shall be at a minimum primer coated with an epoxy coating. Coating manufacturers should be consulted for appropriate coating materials and application methods for the operating temperature range of the equipment.

The presence of leachable chloride or certain other elements has been found to exacerbate corrosion. Too often the search for the source of such ions has been centered incorrectly on the insulation system components, rather than an external environmental factor which is more often the cause.

Chemical exposure is the final major environmental element affecting CUI. Acids and acid gases, hydrochloric acid, sulfuric acid, strong bases (caustics), and salts are aggressive corrosive agents and will both cause and accelerate CUI. The complexity of addressing the reaction of various metals to corrosion by chemicals is beyond the scope of this Technical Bulletin.

OXIDATION

Oxidation (or simply rusting) is sometimes referred to as *uniform corrosion,* and is one of the most common mechanisms for corrosion of carbon steel pipe; oxidation does not occur on stainless steel. Oxidation of carbon steel involves four requisites:

1. *High* temperature
2. Moisture
3. Oxygen
4. Concentration of corrosive ions

It is an inescapable fact that iron in the presence of oxygen and water is thermodynamically unstable with respect to its oxides. Because oxidation corrosion is an electrolytic process, the presence of an electrolyte is required. This should not be taken to mean that the steel surface must be awash in water; a very thin adsorbed film of water is all that is required.

Oxidation on carbon steel pipe can occur between 32°F and 300°F; the “optimum” temperature range for aggressive corrosion seems to be between 200°F and 240°F[5]. In this range, there is plenty of heat energy but not enough heat to efficiently evaporate moisture before it contacts the equipment surface. Corrosion rates can double for every 18°F rise in temperature[6].

At the service temperatures considered in this paper (below freezing point of water), the temperature should be insufficient to precipitate corrosion even if water, oxygen, and chloride ions are present. Yet, virtually all piping systems spend some time at ambient temperatures, such as during shutdowns for maintenance. Thus there must still be an exerted effort to minimize moisture and the presence of chloride or other environmental contributors or catalysts. An insulation engineer should be consulted when a carbon steel mechanical system cycles into service

[5] “Is There a Cure for Corrosion Under Insulation?” Michael Lettich, National Insulation Association, http://www.insulation.org/articles/article.cfm?id=IO051101

[6] Mechanical Integrity and Carbon Steel Refrigerant Piping, Daniel J. Dettmers and Douglas T. Reindl, ASHRAE Journal, October 2007

temperatures between 32°F and 300°F for more than 20% of the time. Typical practice in such circumstances is to apply an epoxy coating, or equivalent.

PITTING (OR CREVICE) CORROSION

Pitting corrosion is a broad term for corrosion that either begins within *pits* (non-uniformities) in the pipe surface, or causes pits. Pipe failure can occur if a pit fully penetrates the pipe wall. Pitting can occur in both carbon steel and stainless steel pipes, although it is more commonly associated with stainless steels. Pitting is often considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict and design against.

Generally, pitting on pipe exteriors can be associated with:

- Localized chemical or mechanical damage to the protective oxide films in carbon steel;
    - chemistry factors such as acidic rain or high concentrations of chloride (as in *salt air* that has penetrated the insulation system, or indeed from a poorly selected insulant itself in certain circumstances) can cause breakdown of a passive film; and/or
- The presence of non-uniformities in the metal structure of the component (e.g. nonmetallic inclusions); and/or
- Localized damage to the protective chromium oxide layer on stainless steel (such as at manganese sulfide inclusions on the steel surface) caused by:
    - chloride or chlorine-containing ions
    - bromides (fluorides and iodides are not aggressive)
    - cupric, ferric and mercuric ions (such ions may act in concert with chloride to promote pitting without dissolved O_2) [or may indeed prevent pitting in a phosphoric acid environment (e.g. it's complicated)];
    - thiosulphate ions (S_2O_3) may also promote pitting.

Metals that are susceptible to uniform corrosion (e.g. carbon steel) do not tend to suffer from pitting. Thus, carbon steel will corrode uniformly in sea water, while stainless steel will pit. An addition of about 2% of molybdenum increases pitting resistance of stainless steels.

Note that *crevice corrosion* takes place where physical crevices are present, such as at the joint between two overlapping sheets of stainless steel, in the crevice between a stainless steel flange and a non-metallic gasket or under surface deposits.

STRESS CORROSION CRACKING

SCC is the initiation and propagation of micro-cracks caused by the combined effects of tensile stress coupled with direct surface contact with an enabling chemical[7]. The stress can be externally applied, thermal, or residual from the manufacturing process. This stress, coupled with a susceptible material and environment, causes small cracks inherent or formed in the material to propagate - - thereby relieving the material's stress. If the stress level is low, the cracks will self-limit (stop propagating) prior to fully penetrating the pipe wall. If the stress level is high, the cracks have the potential to propagate completely through the entire wall thickness, resulting in a leak.

Contrary to conventional wisdom, Stress Corrosion Cracking (SCC) can occur in carbon steels as well as stainless steels. Yet SCC in carbon steel pipes is unusual on the exterior of the pipe since it requires exposure to either hydroxides, nitrates, carbonate, bicarbonates, liquid ammonia, or $CO/CO_2/H_2O$ at very low temperatures. SCC in carbon steel is more of a concern on the inside the pipe in certain ammonia refrigerant applications/conditions where oxygen may be present.

The most common form of SCC in mechanical systems within the temperature ranges addressed in this document is chloride stress corrosion that occurs only in stainless steel pipe, which involves five prerequisites:

1. *High* temperature
2. A threshold of chloride (or fluoride or similar) ions
3. A threshold of moisture (dissolved oxygen)
4. Metal under tensile stress
5. Time

Chloride SCC can occur between 140°F and 300°F for 300 series stainless steel. The "optimum" temperature range for aggressive corrosion on 300 series stainless steel seems to be between 200°F and 240°F. The *threshold* of chloride ions necessary to initiate SCC varies with the other four variables above. The threshold does not need to be zero, and there are decades of empirical evidence that a low chloride content in commonly used low-temperature insulants does not lead to SCC.

Chloride SCC can also be overcome by using a duplex stainless steel, such as 2205, or a grade with a higher nickel content, such as a 6% Mo material or high-nickel alloys like Alloy 825 (N08825). Ferritic stainless steels are very resistant to SCC but grades with equivalent pitting resistance to the austenitic grades have other major drawbacks.

[7] American Society of Materials International. 2003. ASMI Handbook Volume 13a, Corrosion: Fundamentals, Testing, and Protection, "Selecting Materials to Prevent or Control Corrosion."