Corrosion of Steel and Stainless Steel Under Thermal Insulation: A Technology Transfer Between the Chemical Processing Industry and the Radioactive Materials Packaging and Transportation Industry

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INTRODUCTION

The proliferation of corrosion failures of both steel and stainless steel under insulation in recent years has caused this problem to be of great concern to the operators of petroleum, gas and chemical processing plants. We now welcome this opportunity to take part in this technology exchange with PATRAM members.

Piping and vessels are insulated for a purpose: i.e., to conserve energy by keeping cold processes cold and hot processes hot. Once a vessel is covered with insulation and operates in a satisfactory manner, concern for the condition of the metal under insulation usually fade. Thus, corrosion of steel and stress corrosion cracking of stainless begins and develops in an insidious fashion, often with serious and costly consequences many years later.(ASTM1984)

In order to effectively and economically deal with corrosion under insulation, a systems approach needs to be developed which considers the metal surface, temperatures, water, insulation, and design.

CORROSION OF STEEL UNDER INSULATION

The Problem

Steel does not corrode just because it is covered with insulation. Steel corrodes when in contact with water and a free supply of O_2. The primary role of insulation is to produce an annular space wherein water can collect on the metal surface and remain, with full access to oxygen.

The most active sites are those where the steel passes through the insulation and on to horizontal metal shapes, i.e., insulation support rings where water can collect. Another major corrosion problem develops in situations where there are cycling temperatures which vary from below the dew point to above ambient. In this case, the classic wet-dry cycle develops when the cold metal develops water condensation which then is baked off during the hot-dry cycle. The transition from cold-wet to hot-dry includes an interim period of damp-warm conditions with attendant high corrosion rates. An example is shown in Figure 1. If the line had operated constantly either cold or hot, no significant corrosion would have developed.

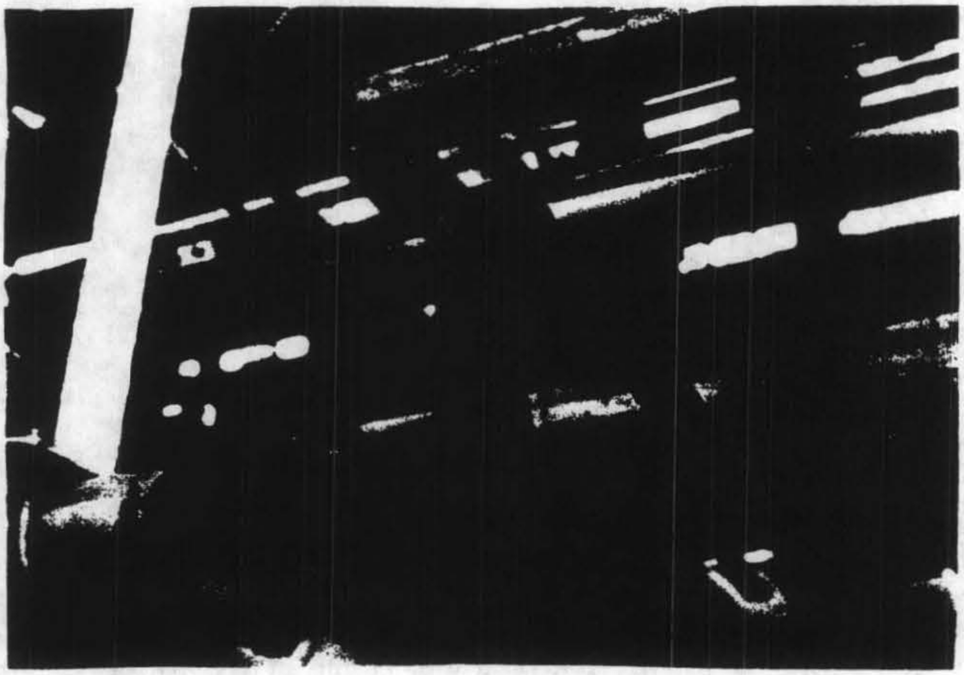

FIGURE 1. Heavy general corrosion of a steel line insulated with cellular glass and aluminum outer jacketing. This is a "blow down" line which is normally at ambient temperature except when it is used to vent hydrocarbons to a vent header. Then the line becomes cold, causing moisture condensation followed by warming to ambient and slow corrosion. This line had to be replaced after eleven years of service.

The Mechanism

The corrosion rate of steel in water is controlled largely by two factors: (1) temperature and (2) availability of oxygen. In the absence of oxygen, steel corrosion is negligible. The early corrosion literature clearly illustrates this point.

In an "open" system the oxygen content decreases with temperature to the point where the corrosion decreases even though the temperature continues to increase (Figure 2).

A number of recent case histories of corrosion under insulation have been reviewed and the estimated corrosion rates have also been plotted on Figure 2. This field data confirms that the corrosion of steel under insulation increases steadily with increasing temperature.

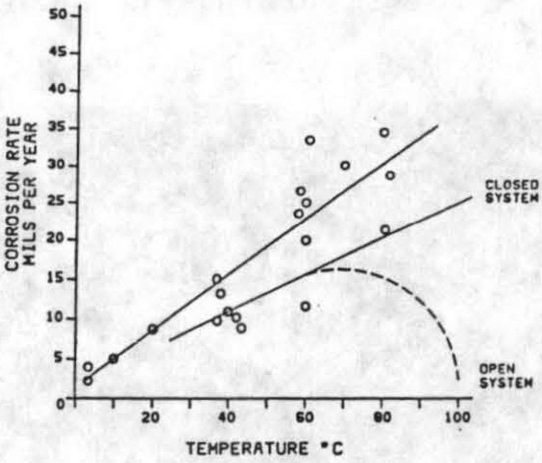

FIGURE 2. Corrosion of steel in water as influenced by temperature.

o Data points from actual plant measurements of corrosion under insulation.

The thermal insulation does not corrode the steel, but more correctly forms an annular space where moisture collects. The insulation also forms a barrier to the escape of water or water vapors thus aggravating the normal corrosion rate of wet steel. Thermal insulation materials containing acids can lower the pH of the water thereby greatly increasing the corrosion rate.

At this point, the question usually arises "which insulation contributes most to the corrosion of steel, and which the least?" In an attempt to determine this point, Laundrie and Ashbaugh(1980). conducted tests comparing twelve common insulation materials. The general conclusion of the test was that those insulation materials that absorb water developed higher corrosion rates than those that did not, the difference between the two however, was not great. Therefore, efforts to select a type of insulation to prevent corrosion would not solve the problem. Field observation and reports from the literature confirm that corrosion of steel occurs under any and all types of insulation. The phenolic foam insulation used in the UF6 overpacks is not used on petrochemical equipment and thus was not tested.

Prevention

If water ingress to the insulation/steel annulus is the problem why not do a better job of "water proofing"? Improvements in various metal jacketings, sealants, and mastics have definitely improved the protection of insulation materials from water, weather, and humans. Can these waterproofing systems prevent water ingress? We suggest they cannot because in order to seal and prevent the annulus from breathing, with temperature changes, the seal would have to be equivalent to a pressure vessel!

Selection of insulation, inhibiting the insulation, and waterproofing of the insulation are not effective deterrents to corrosion. What is then the preferred approach? A high quality protective coating, correctly applied to the steel before insulation can offer long-lasting protection.

Inspection

The final subject regarding corrosion of steel under insulation is monitoring or inspection. Due to the widespread occurrences of corrosion under insulation, the need for rapid, quantitative, nondestructive testing inspection of the steel has developed. The most common procedure is to cut plugs or windows in the insulation, thus exposing the steel for ultrasonic thickness testing.

This spot thickness testing is relatively accurate, but only covers a very small portion of the vessel or piping. Corrosion under insulation tends to be rather localized and thus spotchecking can miss potential trouble areas. If the insulation becomes wet and retains water it should be completely removed and the entire vessel inspected.

Once the steel equipment has been covered with a good protective coating, the inspection at "windows" can be made less frequently and is only necessary to monitor the condition of the paint. Thickness readings are not necessary unless the paint film has failed.

STRESS CORROSION CRACKING OF STAINLESS STEEL UNDER INSULATION

The Problem

During and after World War Two, many new petrochemical plants were built in the United States. Many of these plants contained equipment built with the austenitic stainless steels. These were widely used to combat process corrosion and to maintain product purity. As in all chemical processes, a large percentage of this equipment was insulated for thermal efficiency. As insulation systems and their weather barrier coatings aged, more incidents of external stress corrosion cracking under insulation (ESCC) began to occur in the chemical process industry. In the years to follow, much work was done to investigate the problem and counter measures.(Danaand DeLong1956)(Ashbaugh1965)(Ashbaugh1983)

The Mechanism

Early in the application of the 18-8 austenitic stainless steel, it became clear that the chloride ion in water could be very damaging. In addition to causing localized corrosion such as pitting and crevice corrosion, rapid failure was seen in the form of a fine network of transgranular cracking. This pattern of cracking is very distinctive and is found on the surface. (See Figure 3).

FIGURE 3. A typical stress corrosion crack of 18-8 stainless steel caused by chlorides under insulation. This major crack is accompanied by the branched network of very fine cracks. Shown approximately natural size.

There are four necessary ingredients for stress corrosion cracking to develop. These are: (1) An 18-8 austenitic stainless steel, (2) the presence of tensile stresses, (3) the presence of chlorides and (4) the presence of an electrolyte (water).

- The stainless steel alloys susceptible to stress corrosion cracking are generally classified as the "18-8's," that is, 18% Cr, 8% Ni, balance Fe (304). This includes the moly containing grades (316, 317), the carbon stabilized grades (318, 321, 347), and the low carbon grades (304L, 316L).

- In order for the stress corrosion cracking phenomenon to develop instead of pitting, sufficient tensile stress must be present in the material. If the tensile stress is eliminated, or greatly reduced, cracking will not occur. The threshold stress required to develop cracking depends somewhat on the severity of the cracking media. Most mill products such as sheet, plate, pipe, and tubing contain enough residual processing tensile stresses to develop cracks without external stresses. When the 18-8 stainless steel alloys are cold formed and welded, additional stresses are imposed. As the total stress rises, the stress corrosion cracking becomes more severe.

- The chloride ion is a specific for damaging the passive protective layer on the 18-8 stainless steel alloys. Once the passive layer is penetrated, localized corrosion cells become active. Under the proper set of circumstances, stress corrosion cracking can lead to failure in only a few days or weeks. Sodium chloride, because of its high solubility and widespread presence in the earth,s crust and seas, is the most common culprit. Lowering the pH also increases the rate and severity of stress corrosion cracking.

  The question most asked and hardest to answer is "what concentration of chlorides does it take to initiate stress corrosion cracking?" Researchers have developed cracking in solutions with remarkably low levels of chlorides (i.e. less than 10 ppm). The situation of chlorides under insulation is unique and ultimately depends on the concentration of chlorides deposited on the metal's surface. If any chlorides are detected, then the probability is that there will be some localized sites of high concentration and thus "too much."

  The most important condition affecting chloride concentration is the temperature of the metal surface. Temperature has a double-barreled effect; first elevated temperatures will cause water evaporation, which in turn concentrates the chloride salts; and second, as the temperature increases the rate of corrosion reaction increases.

- Water is the fourth necessary ingredient in stress corrosion cracking. Since stress corrosion cracking is an electrochemical reaction, it requires an electrolyte. With stress corrosion cracking problems we say "look for the water." As water penetrates the insulation system, it plays its own special role at the metal surface depending upon the equipment design and operating conditions.

In summary, when the four conditions of stainless steel alloy, stress, chlorides, and water come together, stress corrosion cracking becomes highly probable.

Prevention of ESCC

As we developed an understanding of the stress cracking problem and its mechanisms, the selection of a prevention method become much easier. Just as for steel the best protection aginst chloride stress corrosion is a high-quality protective coating.

The application of any protective coating requires good specifications and inspection. The use of manufacturer application guidelines and an experienced inspector should go a long way toward producing an acceptable protective coating.

SUMMARY

The incidence of chloride stress corrosion cracking of stainless steels from the atmosphere is known to be frequent enough that it should be a consideration in every plant design. Equipment located on, above, or adjacent to the oceans will certainly be susceptible to intrusion of chlorides. As the plant location becomes more and more remote from the sea and from other chloride courses the incidence of ESCC that can be caused by the atmosphere will be reduced. However, local conditions such as water spray, fire water, wash water, process leaks, spills, and vents all may contribute chlorides to the environment.

Stainless steels are selected to perform certain and specific tasks such as corrosion resistance and protecting product purity. The expense of using stainless steel should encourage due consideration of protective measures outlined above to prevent unwanted and untimely failures of such equipment by ESCC under insulation.

In 1995 the NACE Technical Practice Committee T-5A-3a prepared its first draft of a Standard Recommend Practice "To Control Corrosion Under Thermal Insulation and Fireproofing Materials - A Systems Approach." We hope to have this document balloted and approved sometime in 1997.

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