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CORROSION UNDER THERMAL INSULATION AND FIREPROOFING

AN OVERVIEW

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ABSTRACT

This paper presents an overview of the continuing critical problem of corrosion under thermal insulation and also corrosion under fireproofing. Fireproofing (or fire resistant coatings) are applied to thermally protect structural steel and vessels in the event of a fire. Specifically the fire protective materials discussed in this paper are gunite and concrete, both of which afford excellent performance during exposure to high intensity process fires. The overview is based on the author's extensive experience with corrosion under thermal insulation (CUI) and corrosion under fireproofing (CUF) in the petroleum/petrochemical industry.

Keywords: corrosion, thermal insulation, concrete, gunite, polyurethane, cellular glass, perlite, coatings, ESCC, Fireproofing, CUI, CUF.

INTRODUCTION

The period covered in this paper extends from the mid-1950's until the present time. To set the stage, the author joined the engineering department of a major petroleum company in 1954 after graduating from college with a B.S. degree in mechanical engineering. The specific job assignment was with the materials development laboratory in the corrosion prevention and control area. At that time there were no undergraduate courses concerning corrosion or properties of materials, other than metallurgy. Later, in graduate school, a course in corrosion was available and the textbook used was Uhlig's "Corrosion Handbook"(1) printed in 1948. The course was taught by an electroplater who knew the meaning and function of anode, cathode, and electrolyte. There is no mention of corrosion of carbon steel under thermal insulation or concrete in that text nor in Uhlig's subsequent text "Corrosion and Corrosion Control"(2) printed in 1965.

WHAT CORROSION UNDER INSULATION OR FIREPROOFING

From 1954 until the early 1970's there was little to no CUI or CUF of carbon steel equipment. Why ?? There are many reasons but most importantly thermal insulation was not required until operating temperatures of piping, vessels and tankage reached 300°F. Most insulating materials in use at that time were fairly innocuous. In addition, detailed engineering standards were available concerning application of thermal insulation and application of concrete and gunite fireproofing. Extensive design data was included in these standards for concrete and more importantly for gunite which was the material of choice for fire protection. These subjects are discussed in detail in subsequent paragraphs.

External Stress Corrosion Cracking (ESCC) of austenitic stainless steel under insulation was of concern beginning in the mid-1950's with basic R&D carried out by chemical manufacturers and by atomic energy laboratories. The curves for the use of sodium silicate/chloride content to inhibit ESCC were developed by the mid-1960's. Also, large chemical producers were applying protective coatings to austenitic stainless steel under insulation to further prevent ESCC. These areas are discussed subsequently in this paper.

Thermal Insulation

During this period the predominant thermal insulation materials included calcium silicate, mineral wool, asbestos, cork, and cellular glass. The latter two could be used in both hot and cold services. Because of the low cost of energy, tables of appropriate thicknesses of thermal insulation vs. operating temperature were generated and the minimum operating temperature requiring the use of thermal insulation was 300°F (150°C). Cold service thermal insulation was specified for "ice" water, brine and specialty services (whatever that included). Thermal insulation was required for personnel protection at those locations of piping and equipment where workmen might be needed for access or maintenance and the temperature of equipment or piping exceeded 200°F (93°C).

The company's paint and protective coating standard at this time only required painting of carbon steel vessels that were insulated and operated under 200°F. Insulated piping was not coated unless the diameter was greater than 30 inches (75 cms). The paint system specified beneath thermal insulation systems operating below 200° in "normal" environments consisted of hand or power tool cleaning and two coats of an air cured phenolic zinc chromate inhibited primer. For "severe" (probably meaning marine/industrial environments) commercial blast cleaning was specified. The total dry film thickness would be about 3 mils (75 μm) in either case. However, as pointed out in the preceding paragraph little if any thermal insulation was applied below 300°F.

Concrete/Gunite Fireproofing

Concrete/gunite fire resistant coatings had been the materials of choice for many years to protect structural steel and equipment in the event of a fire in refineries and petrochemical plants. Looking back at this early time frame, corrosion under concrete or gunite was not a major action item and it is felt that this was in no small part due to the detailed engineering standards then in use.

The details concerning fireproofing materials and application were specified in extensive engineering standards. Two inches (5 cm) of concrete or gunite were specified for structural steel and 1-1/2 inches (4 cm) for vessels. It was stated that gunite was preferred because its cost was considerably less than concrete and in addition it was "stronger, denser, more durable and less tendency to crack and spall". Its primary disadvantage was "spattering" of the gunite on adjacent piping and equipment and interference with other crafts during its application.

The standards described gunite materials, concrete mix design, water-cement ratios, water quality and testing procedures employed for quality control. Clean, fresh water free from impurities, including chlorides, similar to drinking water was specified. It was stated that brackish and salt water could not be substituted. All steel to be fireproofed was abrasive blast cleaned. However, no protective coating was applied to the steel work. In severe (marine/industrial locations) it was waterproofed by application of two coats of bituminous coating 1/32 in. thick (80 μm) plus a sealer. This was followed by an application of a two compartment aluminum coating (aluminum paste plus vehicle) for appearance.

In addition to the above, additional precautions were specified at all intersections of fireproofed areas and exposed steel, particularly at supports, underside of steel floors and intersection of structural members. Two coats of emulsified asphalt was specified (1/32 in. thick) at these intersections and also sheet metal (read galvanized) flashing was recommended at the top of all fireproofed columns.

In the author's opinion, to select one factor that minimized corrosion under the fire protective coating it was the recommended preferred use of gunite. It is a fact that when the compressive strength of gunite is compared to concrete (3000 psi (21 MPa) was specified) that the strength of gunite can reach 7000 psi (48 MPa). And as stated in the company standards of that time it is much more resistant to weathering even in aggressive atmospheric environments because of reduced water permeability.

THEN WHAT HAPPENED?

Major changes came about in the early 1970's that led to widespread corrosion of carbon steel equipment beneath insulation and fireproofing. Several of these are listed below:

- Cost of energy increased and application of thermal insulation became more cost effective for equipment at much lower operating temperatures.

- New insulation materials were developed and marketed such as organic insulating cellular foams.
- Newer processes came onstream operating at lower and often at cyclic temperatures.
- Thermal insulation was applied to underground pipe.
- Recirculating salt water cooling systems were employed at new facilities.
- There was greater use of austenitic stainless steel piping and equipment.

Also, it was determined that existing detailed standards may have triggered increased capital costs and therefore these were modified in favor of brief, more general basic documents.

Corrosion Under Insulation Sky Rockets

Cost of energy and the energy crisis at this time accelerated the use of thermal insulation for existing heated carbon steel equipment, storage tanks and vessels. Because of this, the use of the new highly publicized, Foamed In Place Polyurethane (FIPP) foam thermal insulation was extensive. CUI began first in Europe and the U.K. at that time because FIPP was touted as a closed cell impermeable insulating material and it was applied in Germany and Holland directly to uncoated steel with no topcoat. A review of major suppliers at that time indicated that there was little if any concern regarding corrosion of carbon steel insulated with FIPP but several indicated that aluminum could be attacked. It was believed that FIPP would be immune to atmospheric weathering and sunlight exposure. Within three years, massive failures resulted and aggressive corrosion had taken place. As an example, one large refinery insulated approximately 150 heated storage tanks by 1973 with FIPP. Within four years, 50% of those tanks required repair because of CUI.

There were other problems associated with FIPP that occurred even after the underlying steel was primed, the foam apparently well applied, and an elastomeric top coat applied over the foam. Large blisters developed that appeared to be caused by moisture on the surface of the steel during application. The application of FIPP depended on an exothermic reaction, causing "blowing" and cell formation by Freon gas. However, examination of blisters indicated a large volume percentage of the gas was CO_2. This is a reaction product of water when it is used as the blowing agent. Such blistering caused cracking of the foam and destroyed the integrity of the surface coating causing additional corrosion problems.

By the 1980's corrosion of carbon steel under thermal insulation was rampant and a worldwide survey indicated corrosion was occurring beneath all types of thermal insulation. Because of the widespread corrosion problems standards were changed to require coating application to all carbon steel when insulated; this was a major step. The operating temperature for this requirement was 30°F (-1°C) to 200°F. However, several facilities only required paint or coating application under insulation between 40°F (4°C) and 150° (65°C) to 180°F (82°C) during this time frame and so corrosion problems continued. Then later the temperature range was broadened to 25°F (-4°C) to 250°F (120°C) and by the late 1980's to 1990's it was again extended to 25°F to 300°F. Other loop holes were closed such as:

+ Protective coatings were required for equipment in intermittent service.
+ Protective coatings were required at lowest operating temperature of equipment; for example the bottom of a tower may operate at 400° (205°C) but at higher elevations it may operate at 180°F (80°C).
+ Vessel stiffening rings could not protrude beyond the insulation system.
+ Thermal insulation on the shell of storage tanks was terminated 12-18 inches (30-45 cm) above ground level.

Additionally, the coating required beneath thermal insulation was changed from a two-coat maintenance primer to a single coat of an epoxy primer (3 mils DFT) to a high build epoxy-phenolic.

Polyurethane foam was also used to insulate underground pipe lines – there is literature that indicated it did not require any anti-corrosive coating on the pipe or an integral external jacket. There were major failures of such pipe because it was felt that cathodic protection systems would protect the pipe when the polyurethane foam was damaged. Testing had shown that protective potentials were achieved at damaged areas on laboratory samples. In the field, cathodic protection was applied and protective potentials measured until the pipeline failed because of shielding by disbonded polyurethane insulation.

External Stress Corrosion Cracking

Before leaving the subject of thermal insulation it would be worthwhile to touch again upon External Stress Corrosion Cracking (ESCC) of austenitic stainless steels when thermally insulated. ESCC of austenitics occurs in a narrow temperature range 150°F to 250°F and the essential elements are stress, an electrolyte, and the presence of chlorides. As discussed previously, it came to the fore in the mid-1950-1960's when ESCC was experienced in chemical plants and the new nuclear submarines. This led to the development of the use of sodium silicate to inhibit ESCC and improved calcium silicate insulation. Chemical plants led the way in specifying the use of protective coatings applied to austenitic stainless steel when thermally insulated and operating in the critical temperature range.

In 1964-1965 an investigation within refineries was undertaken to establish the extent of the problem with ESCC of stainless steels. It was determined that the problem was minimal and although the application of "tailored" paint systems was discussed, this approach was never implemented. However, with the greater use of insulated stainless steel during the 1970-1980 timeframe, the application of inhibited insulation materials was recommended as well as application of epoxy or epoxy-phenolic coatings. Cellular glass insulation was the preferred material. Application of aluminum foil over stainless steel as a barrier to prevent ESCC had been in use for some time in the United Kingdom and this approach was also recommended.

Corrosion Under Fireproofing

Extensive CUF occurred at many facilities during the 1980's to 1990's because of factors related previously; the major causes of corrosion under fireproofing included:

- Inadequate concrete mixes.
- Protective coating not applied because of AISC rules.
- Wrong coating applied.
- No topcoats, sealants or water shedding flashing applied.
- Ineffective designs.

Also much more poured-in-place cast concrete was used reversing the earlier trend to the wide scale use of gunite coatings. This could have been triggered by assertions that gunite was only 50% as effective as cast concrete in the event of a fire.

Inadequate Concrete Mixes

At facilities when corrosion was encountered beneath fireproofing the compressive strength was measured. It was not uncommon to measure compressive strengths of 1500-2000 psi (10-14 MPa) when 3000 psi was specified. In one location the sample of failed concrete had a compressive strength of only 750 psi (5 MPa). At other locations beach sand and/or salt water was used for the concrete mix. For many years the newer basic type documents did not require testing, use of potable water, and did not include the previous severe restriction concerning chloride control. It simply specified 3000 psi compressive strength concrete.

Protective Coating Required

The American Iron and Steel Construction (AISC) handbook[3] specifically stated that coatings should not be applied to steel encased in concrete. It was thought that a protective coating would reduce the adhesion of concrete to steel. This turned out to be erroneous in test work carried out in the mid 1970's and 1980's. Pull out test demonstrated that protective coatings applied to steel developed approximately the same bond strength as that developed when concrete was applied to bare carbon steel reinforcing rod or plain bar stock. The change permitting coating under concrete fireproofing was made in the 1980's.

Wrong Coating Applied

At times inorganic zinc rich coatings were applied beneath concrete; these failed rapidly especially at marine locations and under poor quality concrete. Epoxy protective coatings had been specified to replace the phenolic-zinc chromate initially specified.

Exterior Coatings and Sealants

Exterior protective coatings for concrete fireproofing were not specified for even severe exposures until the late 1980's-1990's. This was also true for sealants, caulks or flashing to seal exposed edges of fireproofing applied to beams and columns.

Ineffective Designs

At one location in a new facility the contractor employed a design for concrete fireproofing that was neither a box design or contour design. Concrete was applied to galvanized steel chicken wire applied at a two inch standoff around the steel column. No protective coating was applied. After only 10 years service there was severe deterioration of the concrete and extensive corrosion of structural steel.

Recirculating Salt Water Cooling Towers

Salt water drift from this type of cooling water tower has caused aggravated corrosion of carbon steel structures, under insulation and also under fireproofing. In several locations employing this type of tower, poor quality concrete had been used for fireproofing and this resulted in extremely low compressive strength concrete. Extensive and expensive CUF occurred at one facility employing recirculating salt water cooling towers after only four years after mechanical completion and startup.

Standards Revised to Prevent CUF

During the 1980's-1990's engineering practices were revised and upgraded concerning fireproofing. The changes included:

- Only potable water could be used for fireproofing mixes.
- Water/cement ratios had to be equal to or less than 0.5.
- Four thousand psi compressive strength concrete was specified in place of the 3000 psi strength concrete specified for years.
- Coating systems under fireproofing were specified and then upgraded.

- In severe environments external protective coatings were specified for new concrete fireproofing. These included penetrants and latex based coating systems.

- Sealants were specified for all concrete/steel intersections.

- Petrolatum tapes were specified for all fireproofed horizontal beams.

In other words, more specific details were added (in some cases added back) to the simplified basic documents which when discarded previously probably led to many of the problems occurring in this time frame.

SO . . . WHERE ARE WE?

There are several approaches to answering this question but the first would be to look at key documents, from a short list, which represent the extensive body of knowledge in this area. These are as follows keeping in mind others might have different selections:

- Work by Dana concerning prediction of ESCC[4].

- Knolls Atomic Energy investigation into inhibition of ESCC by sodium silicate[5].

- Bill Ashbaugh's paper concerning ESCC[6].

- An overview of corrosion of carbon steel by CUI/CUF[7].

- Papers published by ASTM of the proceedings from a conference concerning CUI/CUF[8].

- Papers published by NACE of the proceedings from a symposium concerning CUI[9].

- NACE's Recommended Practice RP 0198[10].

The last would be of the greatest benefit to an individual who recently became involved with CUI/CUF.

An area not covered by any of the above is corrosion under insulation applied to buried pipelines. See the author's paper on this subject[11]. It would be worthwhile to add this subject to RP 0198 when it is due for review in 2003.

Another answer to this question is to look at inspection and Risk Based Inspection (RBI) methodology as applied to this area. Much of the current approach to inspection is found in references 8, 9 and 10. Others have put together their own inspection program but a good starting point again is RP 0198. New NDT instrumentation has been developed such as Neutron Back Scatter, Magnetic Flux Linkage, eddy current and various radiographic techniques have found some use. More recently, facilities have developed and put into place RBI programs which recognize the severe and insidious nature of CUI. However, such programs will depend upon individuals with the appropriate background needed to know where and when to inspect.

Lastly, a third answer to this question can be obtained by evaluating what might be called recent "straws-in-the-wind" that apparently reflect upon the lessons learned and their application. A few of these are based upon the author's experience and discussions with others follow:

- There is continued effort to reduce capital costs by minimizing detailed engineering standards or relying solely upon documents of others.
- Insulated austenitic stainless steel operating in the critical temperature range was not coated because of cost considerations.
- Low temperature sweating carbon steel pipe was insulated but an inadequate vapor retarder jacket was applied.
- A question was recently asked "Has anyone actually seen a case of corrosion of an austenitic stainless steel under insulation?"
- A paper investigating polyurethane foam insulation for use on underground pipe indicated corrosion under polyurethane foam was less severe than corrosion experienced on exposed carbon steel.
- A proposed design for concrete fireproofing would have experienced early failure with severe corrosion of the underlying carbon steel.
- Vessels have been fabricated, coated, insulated, and then transported from the fabrication shop to the construction site.
- In a published article it was advocated that thermal insulation be applied on the shell of an aboveground storage tank down to grade level.

These are, it is believed, decisions and recommendations made and the available technology is either not known or improperly applied. Apparently cost remains a major consideration. Where are we? CUI and CUF will continue but hopefully to a lesser degree than experienced in the past.

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