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A Strategy for Preventing Corrosion Under Insulation on Pipeline in the Petrochemical Industry

The corrosion under insulation war had been fought for many years in the petrochemical industry, but it was perhaps the publication of ASTM STP 880, "Corrosion of Metals Under Thermal Insulation," in 1985 that marked the modern corrosion under insulation (CUI) battle area. This ASTM publication reviewed the causes and factors affecting the occurrence and rate of CUI, the field experience with insulation types and control measures, including the use of coatings; specifications; system design; and inspection. A gap in the inspection procedures noted in STP 880 was an "urgent need to develop a nondestructive on-stream examination (NDE) method to detect corrosion under insulation without the removal of the insulation."

The U.S. Materials Technology Institute responded to this call by funding several studies to determine the effectiveness of NDE methods on detecting CUI. These studies showed that NDE methods could detect CUI. Detection confidence levels increased as multiple NDE methods were used. A single global NDE assessment technique with a high detection confidence level for CUI was not identified. This is still the case today.

NACE sponsored a symposium on CUI during Corrosion 89 and published the papers in a volume titled *Corrosion Under Wet Thermal Insulation*. This symposium was notable both for its emphasis on a systems approach to fight CUI and the presentation of a paper on the use of thermal spray aluminium to prevent CUI. The first NACE report on CUI was published in 1989, as NACE Publication 6H189, "A State-of-the-Art-Report on Protective Coatings for Carbon Steel and Stainless Steel Surfaces Under Thermal Insulation and Cementitious Fireproofing." This report reviewed the history of the use of protective coatings under insulation and fireproofing. Also included in the report were the use of thermal spray aluminium for CUI prevention on insulated carbon steel surfaces, and the long-standing practice of using aluminium foil to prevent stress corrosion cracking (SCC) on austenitic stainless steel surfaces.

In the 1990s, NACE formed a task group to develop a Recommended Practice to prevent CUI. In 1998, this task group published *RP 0198-98*, *The Control of Corrosion Under Thermal Insulation and Fireproofing Materials–A Systems Approach*. This document is the only standard specifically directed at combating CUI. *RP 0198-98*'s emphasis on a systems approach—design, installation, maintenance, and inspection—and its conclusion that the basic solution to prevent CUI is the use of a protective coating marks a milestone in codifying and preventing the problem.

The application of the systems approach and the use of organic coatings have been successful in mitigating CUI on piping systems. However, when the organic coating's protective life is reached, the "out-of-sight" nature of CUI makes it difficult and expensive to detect. For piping systems that are safety, health, environment, or reliability sensitive, an NDE method with a high confidence level of detecting CUI is required. Under these conditions, the inspection costs can equal or exceed the cost of field (maintenance) painting. This has lead to the realisation that the maintenance portion of the systems approach needs to be optimised by concentrating on more fundamental prevention methods as opposed to mitigation and periodic renewal. This article thus reviews a CUI prevention strategy that provides long-term and reliable prevention of CUI. This strategy foremost reduces safety, health, and environmental risks, while moving towards an inspection- free, maintenance-free operating mode that can significantly reduce the need for, and cost of, piping maintenance.

The Cost of CUI

Analysis of leak data shows that over 80% of all CUI leaks occurred in piping. Furthermore, the age of the piping system when the CUI leak occurred is bimodal. One leak population is located at 16–20 years' service life and the second population mean is in piping in service more than 26 years. Examination of the two populations showed that the 16- to 20-year-old population is composed primarily of NPS 4 in. and smaller piping, that is, piping with a relatively low wall thickness. The 26+ year population is composed mainly of NPS 6 in. and greater piping with a heavier wall thickness (Fig. 1).

Table 1: Total Erected Cost (TEC) and Discounted Cash Flow Rates of Return for CUI Prevention Tools

CUI Prevention Strategy	Initial TEC [1]	DCF RR [1]
1. Thermal Spray Aluminium		
New Construction	95% to 105%	30 to 40%
In-situ Maintenance	105% to 120%	20% to 40%
2. Use of Personnel Protection Cages[2]		
New Construction	95% to 105%	
In-situ Maintenance	85% to 90%	
3. Al-foil on Stainless Steel		
New Construction	97% to 99%	
In-situ Maintenance	93% to 95%	
4. Small Diameter Stainless Steel Pipe		
New Construction	115% to 125%	15% to 25%
5. Non-painted (Bare) CS Pipe		
New Construction	60% to 80%	
6. NDE @ High Confidence Level		
In-situ Maintenance	95% to 100%	

1: Organic coating = 100% 2: vs. insulation costs

Two facts to consider with the leak data analysis are: (1) all the pipe was protected by organic coatings before installation and (2) our experience is that the protective life of organic protective coatings on piping in CUI service ranges from 5 to 13 years. When considered with the leak data, this indicates that as facilities age, at least two waves of CUI leaks will occur. The first wave will be composed primarily of smaller diameter pipe, but the second wave will probably include pipe of many sizes spread over a wider range of service years.

CUI cost studies have shown that:
• 40 to 60% of pipe maintenance costs are due to CUI;
• NDE / inspection costs with a high confidence level for detecting CUI are equal to or exceed field painting costs; and
• approximately 10% of the total maintenance budget is spent repairing damage from CUI.

CUI prevention methods that provide longer term CUI protection have the potential to significantly reduce piping maintenance costs by moving towards an operating mode that requires less inspection and less maintenance.

CUI Prevention Methods

Current petrochemical industry CUI management plans include all or most of the following elements:
• insulation system design and installation to exclude water;
• application of an organic coating;
• periodic stripping, abrasive blasting, repainting, and re-insulating; and / or
• on-going periodic NDE / inspection activity.

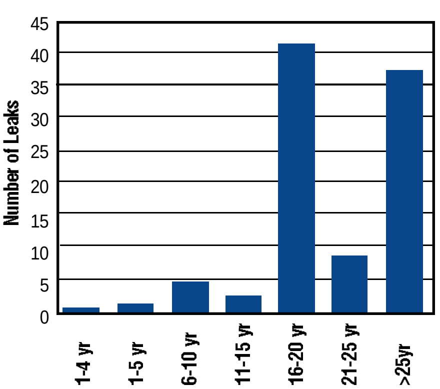

Fig. 1: Analysis of CUI Leak Data

Once the protective life of the organic coating is reached, field re-painting is necessary to maintain a low risk of leaks, or on-going, periodic NDE activities are necessary to monitor the rate of CUI and quantify the piping system's remaining life.

The CUI prevention measures discussed below are based on practices common in the petrochemical as well as other industries, but are characterized by their ability to provide longer term CUI prevention. They maintain a low-failure potential over their longer life cycle and are, therefore, not as dependent on maintenance and inspection activity to manage CUI.

Effects of corrosion under insulation near angles on steel

Thermal Spray Aluminium (TSA)

TSA application by electric arc or flame spray has been described in several publications,[1,2,3] so it will not be repeated in this article. TSA has provided atmospheric corrosion protection for over 40 years on structures such as bridges, locks, and penstocks.[4,5] The U.S. Navy started developing TSA for CUI prevention in the late 1970s. These experiences have been standardized in DOD-STD 2138, "Metal Sprayed Coating Systems for Corrosion Protection Aboard Naval Ships."

This development effort established that TSA is capable of providing long-term protection in severe CUI environments at significant life cycle cost savings.[6] Initial costs, however, have been higher than organic coatings, and this has slowed the spread of TSA to other industries. More recently, the development of equipment with higher deposition efficiency and greater mobility has helped reduce initial cost[9] and increase market penetration, especially in the petrochemical industry.

Stainless Steel for Small Diameter Piping

Small diameter piping (3 NPS or less) appears to be prone to CUI leaks because of its low wall thickness, the increased number of field welds, the coating's inefficiency, and the human tendency to pay less attention during handling, maintenance, and inspection. Stainless steel piping would solve the CUI concerns in many services but initial cost and the possibility of external stress corrosion cracking or pitting have been impediments to wider use. Al-foil wrapping now presents a low cost, proven option for preventing external stress corrosion cracking and pitting, leaving the initial cost issue as the outstanding item.

The bad news is the initial cost of stainless steel piping is still 15 to 25% higher than the initial cost of painted carbon steel piping, but the gap is narrowing. The price of stainless steel is lower today than it was 30 years ago, while the cost of carbon steel has more than tripled. Stainless steels are now a volume product with a continuous growth rate averaging 5% per year while carbon steel volumes are almost steady. The volume growth of stainless steels has been at the expense of the carbon steel market, and the driver for stainless steel product development is life cycle cost savings versus carbon steel.[8]

Market forces are expected to continue the long-term downward trend on stainless steel prices. However, even at today's prices and at equal schedules, the life cycle cost savings for stainless steel piping versus painted carbon steel can be significant. Small diameter stainless steel piping has a role to play in selected applications to prevent CUI.

Personnel Protection Cages

Thermal insulation is used to protect workers from hot surfaces and conserve energy. In services where the thermal insulation is applied only for personnel protection, wire "stand-off" cages can replace the insulation. These cages are simple in design, low in cost, and free of concerns with CUI.

The initial cost of personnel protection cages is 5 to 15% less than the installed cost of thermal insulation, and, again, life cycle costs are a bit lower than those for organic coatings. Personnel protection cages have been used in the petrochemical industry for over 30 years. Their use now appears to be growing as companies continue to explore ways of reducing initial and on-going maintenance costs.

Al-foil Wrapping of Stainless Steel Pipe

CUI appears on stainless steel pipe in the form of stress corrosion cracking or pitting. Cathodic protection has been recognized as an effective means of preventing stress corrosion cracking or pitting on austenitic stainless steel for a number of years, and aluminium has been established as an effective anode for use on stainless steel piping.[7]

ICI pioneered the use of Al-foil to prevent external stress corrosion cracking and pitting on stainless steel pipe. Those efforts started over 40 years ago and at last report in 2000 have been complete-

ly successful. The use of Al-foil as the anode was an inspired idea: it is readily available, easy to install, and low in initial cost.

This technique is widely used in Europe by end users and engineering companies and is covered in NACE RP 1098-98, but has been slow to be accepted widely in North America.

Organic Coatings for Carbon Steel

Organic coatings are the primary corrosion control for CUI today, and will remain imortant in the future, especially for maintenance of existing piping systems or in hot work restricted areas. However, the weak points of thin-film organic coatings are their brittle nature—which leads to nicks and scratches during pipe handling and installation—and their permeability. These weaknesses are especially problematic in CUI services with risks to safety, health, the environment, or reliability.

Coating manufacturers must develop product formulations with improved permeation resistance in order to increase the service life of pipeline coatings. Better permeation resistance will keep the economics of organic coatings attractive. Many manufacturers now have new formulations specifically intended for CUI protection, with claimed upper temperature and wet heat resistance at least 100 degrees C (180 degrees F) higher than that found in coatings 10 years ago. Continued development and evaluation of organic coatings remains an important contribution to CUI prevention technology, even as we rely more heavily on other solutions.

The Cost of Deploying CUI Prevention Measures

Two economic concepts are frequently posed as questions when deciding whether to fund a project or perform a maintenance operation. The first question is frequently “Will it cost more?” while the second is “Will it make us money?” Both questions are interrelated and rooted in the economic analysis technique of discounted cash flow (DCF). DCF is based on the principle that money spent today (the initial cost in the “will it cost more” question) has more value than money spent tomorrow (cash flow) because the money spent tomorrow is “discounted” usually by an internal company-specified investment return rate. Likewise, the rate of return can be calculated based on the initial cost and the cash flows to answer the “will it make us money” question. If this rate of return exceeds a minimum rate specified by the company, the total expense (initial cost + cash flows) is a good investment.

If the initial cost is competitive with the initial cost of other options, the money saved at a later date and discounted can overcome the increased initial cost and produce a high rate of return. If the initial cost is significantly higher than that for the other options, the money saved at a later date and discounted will not off-set the higher initial costs and return rates will be lower or even negative.

Total erected cost (TEC) is the other concept that is important in this discussion. TEC is the sum of the direct and indirect costs associated with a job. It includes the direct material costs, all direct labour, and other direct costs to fabricate, demolish, and dispose of equipment. Indirect costs include supervision, equipment rentals, and related items. It is not unusual for indirect costs to approach the level of direct costs. TEC is important because it provides a more realistic view of the costs for deploying CUI prevention measures. For example, a new coating might cost two or three times as much as the coating currently in use, and specification of the new coating might be discouraged on this basis.

However, on a TEC basis, the costs of the new coating may be within a few percent points of existing practice because the other cost elements that make up TEC, like pipe materials and fabrication costs, are significantly higher.

Table 1 (p. 44) compares the TECs and discounted cash flow rates of return for CUI prevention measures. The following observations are reflected in the data in Table 2 (p. 50) and form the basis for the CUI strategy discussed below.

1. The choice of a 2- or 3-coat organic paint system did not have a significant effect on the TECs.
2. The decision to use a sealer on TSA does not have a significant effect on the TECs .
3. TECs of piping replacement projects are strongly influenced by pipe material and fabrication costs; TECs are relatively insensitive to pipe coating costs. (Coating costs between $1.00 and $15.00 per square foot are used in Table 2.)
4 . The cost of detecting CUI by nondestructive examination at a high level of confidence is about equal to the in-situ maintenance costs for painting because the other TEC cost elements (like insulation, stripping, scaffolding, etc.) have a stronger influence.

CUI Prevention Strategy

Two CUI prevention strategies are contrasted. The first is the conventional CUI mitigation strategy. This approach is based on painting and / or inspection (NDE) at repeated intervals during the life of the piping system. In this strategy, the periodic expenses to maintain the piping system in leak-free condition will be about the same (in constant dollars) because the TECs of field painting and NDEs at high confidence levels are approximately equal to each other. Furthermore, repainting or NDE must be ongoing activities because organic coatings have a 5- to 13-year predicted life, and NDE does not prevent CUI. Rather, it improves the prediction of the remaining equipment life due to CUI.

The second strategy is deployment of any of the four CUI prevention measures discussed in this article: TSA, Al, stainless, and coatings on the same

Table 2: Economic Comparison of Conventional CUI Mitigation and CUI Prevention Strategy Applied to 1500 Feet of NPS 8 Pipe

Cost	Replace Existing CS Pipe with TSA CS Pipe	Replace Existing CS Pipe with Painted CS Pipe; Paint Every 10 Years	TSA Existing Cs Pipe In-situ; Stripe Coat; Re-insulate	Paint Existing CS Pipe In-situ; Paint, Re-insulate, Repaint Every 10 Years
Initial Cost (Yr O) (USD)	643,030	628,950	308,566	255,400
Yr 10 Cost	—	378,000	—	378,000
Yr 20 Cost	—	560,000	—	560,000
Life Cycle Cost	643,030	1,566,950	308,566	1,193,400
NPV@10%	643,030	858,105	308,566	484,554
DCF Rate of Return	39%	—	24%	—
Initial Cost per ft^2	189.00	185.00	91.00	75.00
Annualised Cost/Sq Ft/Year(20Yr)	9.44	23.01	4.53	17.52

Notes
- Cost basis is 2002 U.S. Gulf Coast data; inflation assumed at 4%
- At NPS 3 and below 304 stainless steel pipe may be cost effective
- Personnel protection cages should be used to eliminate thermal insulation whenever possible
- TSA to Paint costs used for this analysis, 7:1 ratio for replacement cases and 12:1 ratio for in-situ cases
- NPS = nominal pipe size
- Re-paint costs may be painting or NDE costs
- CS = Carbon steel

pipeline. Each of these measures allows for preventing CUI while providing longer life cycles. Each of the measures in the second strategy presents the opportunity for a do-it-once approach and moves towards an "inspection-free, maintenance-free" operating mode. Each of these measures results in low life cycle costs, low failure (leak) rates, and consistent low risk without the need for large periodic maintenance or inspection expenses. The return rates on this strategy are good because initial costs on a TEC basis are competitive with the conventional approach.

Table 2 compares the economics of the conventional CUI mitigation and CUI prevention strategies. For piping systems that are safety, health, environment, or reliability sensitive, deployment of the longer life CUI prevention measures is justified on a risk basis and is now also attractive on an economic basis. For piping systems that are not safety, health, environment, or reliability sensitive, strategies can be evaluated primarily on an economic basis. Painted carbon steel or non-painted carbon steel, replaced periodically and not inspected, may be a good strategic choice.

Conclusions

CUI may account for 40–60% of a company's piping maintenance costs, or about 10% of a company's total maintenance budget.

The basic solution to CUI is the use of a protective coating under the insulation within the framework of a systems approach—design, installation, maintenance, and inspection—to prevent CUI. CUI prevention measures that provide long-term and reliable CUI protection are available at initial TECs that compete with current coating systems and provide good returns compared to current coating systems.

The incremental cost of CUI detection by NDE with high detection confidence levels for CUI versus deploying one of the CUI prevention strategies is small. A CUI prevention strategy such as TSA, Al, stainless, or a protective coating system that provides long-term and reliable prevention of CUI can reduce maintenance and inspection costs while maintaining low rates of piping failures from leaks.

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