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Biodegradable Method of Corrosion Management for All Industries

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ABSTRACT

The annual cost of metallic corrosion worldwide is staggering when you take into account the cost of maintenance, prevention, replacement of parts, and interruption of services due to corrosion caused failures. This paper focuses on the most effective and latest technology in corrosion prevention for protection of boiler systems, turbines, pumps, storage tanks, HRSG systems, generators, and piping systems. In technical terms, protection of the system is based on "temporary" corrosion inhibitors -- inhibitors that can easily be removed while providing extended protection for interior void spaces of equipment or entire systems for predetermined time intervals. Volatile corrosion inhibitors (VCI) solutions allow for quick application, minimum maintenance during equipment storage, and minimal work in removal: critical to start up time and cost when returning equipment to service.

Key Words: Asset, equipment, preservation, volatile corrosion inhibitors, mothballing, storage

INTRODUCTION

Widespread research has been done on the topic of corrosion, mothballing and layup procedures using VCI.[1] It is estimated that corrosion will cost the US economy over $1.1 trillion in 2016. This estimate is based on the 1998 NACE study NACE Corrosion Costs Study showing the cost of corrosion to be $286B generalized to 2016 using the inflation index.[2, 3] At over 6.2% of GDP, corrosion is one of the largest single expenses in the US economy yet it rarely receives the attention it requires. As it stands, corrosion is one of the largest costs to the U.S. economy, only exceeded by health care and real estate in total spending per year.

US demand for corrosion inhibitors is forecasted to rise 3.1 percent per year to $2.8 billion by year 2020; volume will approach 1.7 billion pounds. Global demand for corrosion inhibitors will reach $7 billion for the same time frame as demand will grow by faster pace than in the US in developing countries such as China, India and Brazil to name a few. Organic corrosion inhibitor (including VCIs) demand will account for nearly one-third of the market on a volume basis and one-half on basis of selling price by year 2020.[3] It is estimated that the power industry will spend $550M/yr. by the year 2020 (Figure 1).

Summary Table
Corrosion Inhibitor Demand
(million dollars)

Item	2010	2015	2020	2025	% Annual Growth 15/10	% Annual Growth 20/15
Gross Domestic Product (bil $)	14964	17950	22450	27950	3.7	4.6
$ corrosion inhibitor/mil $ GDP	138	136	125	117	N/A	N/A
Corrosion Inhibitor Demand	2060	2450	2810	3280	3.5	2.8
Petroleum Refining	465	545	600	660	3.2	1.9
Utilities	445	480	550	615	1.5	2.8
Chemical Manufacturing	375	420	505	605	2.3	3.8
Oil & Gas Production	270	390	460	600	7.6	3.4
Metals	195	255	295	340	5.5	3
Pulp & Paper	145	150	160	180	0.7	1.3
Other Markets	165	210	240	280	4.9	2.7
$/lb	1.38	1.52	1.66	1.8	2.0	1.8
Corrosion Inhibitor Demand (mil lb)	1490	1615	1695	1820	1.6	1.0

Source: The Freedonia Group

Figure 1: Corrosion Inhibitor Demand (millions dollars).[4]

Power plants provide an excellent example; and the contribution of each component described below is calculated through a life-cycle cost analysis assessment that allows determination of the annualized value of each type of corrosion. Alternative approaches to corrosion management can then be annualized into up-front capital costs and maintenance costs over the life of structures. The operator or owner can then make decisions based on the direct cost analysis with corrosion included as a factor.

The management-related costs of corrosion control include:[2]

– corrosion-related inspection,
– corrosion-related maintenance,
– repairs that are required due to corrosion,
– replacement of corroded parts that are found during inspections or operation,
– inventory and maintenance of backup components,
– rehabilitation and refurbishment, and
– loss of productive time for operation.

VCIs provide an alternate method of corrosion protection of components and systems with complex internal geometry and/or extensive piping runs.

DISCUSSION

As stated VCI come in many different delivery systems, which make them applicable across all industries and applications. However, the goal of this paper is to concentrate on the liquid VCI, which can be volatized/ fogged into internal systems. The benefit of fogging is it creates infinite surface area for the inhibitor to volatize from and more quickly reaches all remotes corners and crevices of the enclosed volume.

VCIs work on the principal of Fick's Law of Diffusion and like perfume, cologne, or air fresheners emit a vapor until they reach their equilibrium pressure in an enclosed volume. Once equilibrium pressure is obtained the source stops emitting analogous to a pressure switch. The vapor is adsorbed by the metal surface neutralizing the electrical surface charge of the metal forming a molecular layer to protect against corrosion caused by oxygen, carbon dioxide, hydrogen sulfide, sulfuric acid, and hydrogen chloride.

Another aspect of (VCI) is the environmental impact; the majorities of VCI products are low in Volatile Organic Compounds (VOC), carcinogens, have low toxicity and do not pose health or disposal issues. Many products are based on renewable sources such as corn, sugar beets, soybeans, soya seeds, citrus, coffee, and coconut and canola seed. Water, solvents and petroleum products are also used as carriers for the VCI. The VCI can be delivered to the metal surface using film, paper, open cell foam, powder, and fluids; and can be applied by brushing, rolling, dipping, spraying, injecting, fogging, wrapping and including in existing processes. By combining the multiple delivery systems with the different carriers, it is possible to customize each application to minimize impact on cost, schedule, maintenance, reliability, the need to remove prior to equipment use and term of corrosion protection.

Unlike nitrogen blankets, dehumidification systems and contact inhibitors such as other wax-based products, VCI products do not require hermitic seals, power sources to be effective nor do they need to be removed prior to use, if properly chosen.

In a study conducted at the University of California, Northridge corrosion data have demonstrated that vapor phase corrosion inhibitors have superior advantages over nitrogen blanketing system in the presence of excessive salt and moisture. On average, the LPR corrosion rate measured less than 0.06 mpy for samples immersed in and exposed to the VCI solution with no signs of corrosion. The immersed and nitrogen blanketed samples, in contrast, showed a corrosion rate of 1.78 mpy and were covered with a thick red rust. The ER probes showed a corrosion rate of 0.18 mpy for the VCI treated samples, while the nitrogen blanketed samples showed a 2.12 mpy corrosion rate and the probes were heavily corroded. It is interesting to report that when VCI was injected into the nitrogen blanketed corrosion cell, the corrosion rate of the corroded steel probes dropped to less than 0.26 mpy in less than 20 hours, and eventually to less than 0.04 mpy after 72 hours. This shows a significant reduction in the corrosion rate by more than eight times.[5]

The University of California, Northridge also conducted a study comparing the effectiveness of VCI product against a Dry Air (dehumidification) process. In this investigation the corrosion behavior of carbon and galvanized steel samples were tested in two environments containing 200-ppm chloride solution; the first test environment used 10% inhibitor and was compared with samples placed in dry air (at 20 psi applied pressure) where moisture levels were maintained at less than 40% RH. The corrosion rate of the exposed samples was monitored for more than six months using electrical resistance (ER) probe techniques. The data demonstrated that the inhibitor provided superior corrosion protection for the steel samples. The samples in the dry air system suffered corrosion attack and red rust formation after 21 days. The ER probes showed a corrosion rate of less than 0.08 mpy with inhibitor, while the dry air samples showed a 1.6 mpy corrosion rate and the ER probes were heavily corroded.[6]

Whereas products such as wax-based products[7] protect only in the contact phase resulting in the need to be able physically contact the surface to be protected. VCI products on the other hand are both contact and vapor phase inhibitors and thus do not require physical contact or line of sight to protect metal surfaces. The VCI will volatize and migrate to all void spaces in an enclosure no matter how small or tortuous the flow path maybe until equilibrium is reached and all surfaces have a molecular film covering.

The use of VCI products eliminates, the concerns due to loss of power (nitrogen blankets and dry air systems), the need to purge a space for re-entry after application of inhibitor (nitrogen blanket) and the need to have equipment on hand to reapply inhibitor and maintenance personnel to monitor the equipment to make sure the inhibitor process is working.

When viewed from a total cost perspective, VCI products provide a cost effective environmentally friendly method of long-term corrosion protection (24-months) with minimal to no inspection intervals. This concept is applicable to all systems and all components through the life cycle of a plant, beginning with the manufacture of equipment, through construction, into operation, operational and critical spares protection, T&D and ultimately lay-up due to market prices and/or decisions to repurpose or decommission and dismantle.

Example of Applications

- Prevention of dew point corrosion on the back end of HRSG
- Flow path protection during construction, shutdown and as spares for pumps, turbines, piping
- Protection of electrical and electronics during construction, operation and as spares
- External machined surfaces with temporary or permanent coatings that do not support rust blooms if coating is damaged
- Protection of tube side and shell side for heat exchangers, boilers, HRSG, condensers during construction, shutdown and spares
- Protection of cooling towers during construction, operation, and shutdown

Length of Protections

The length of protection plays a key role in determining the corrosion protection needed such as short-term, intermediate, or long-term shutdowns. These may be scheduled maintenance completed quarterly, bi-annually, annual inspections or unscheduled maintenance due to equipment malfunction(s);

- Short-term shutdowns may consist of one day, an overnight, or even thru a weekend. This shutdown period is typical of cycling operations and may be a wet layup or hot standby approach. Wet layups are commonly considered for shorter durations of a weekend or one to two weeks, but it can be effective for months, if they are properly implemented and maintained. Dry layups are effective even for the shorter durations, but it may be anticipated to avoid draining the equipment if the unit(s) could be returned to service on short notice.
- Intermediate shutdowns are may be longer than a weekend and maybe upwards to a few weeks. This shutdown duration may be due to scheduled or unforeseen minor equipment malfunctions/repairs.
- Long-term shutdowns are ones that can extend from a few months to three years. Long-term shutdowns are primarily due to major equipment repairs, a scheduled outage, or a long-term layup due to plant requirements with may include “mothballing” equipment.

The potential for corrosion and the highest potential risk for equipment malfunctions are during the equipment’s outage and are based primarily on the duration of the outage. Initial corrosion and mothballing of the equipment should be considered and implemented prior to and during equipment shutdown. It is during the initial shutdown that the elevated temperatures, warm air, and moisture are existent where the corrosion process initiates.

In addition, frequent short-term outages due to seasonal maintenance, unforeseen malfunctions, etc are more destructive than traditional longer-term outages, primarily due to the increased load levied on the equipment due to the more frequent equipment cycling, thus affecting the equipment's life expectancy.

Cost of VCI Versus Traditional Mothballing Methods

Total cost of preservation can be determined based on the specific method chosen, such as nitrogen blankets, dehumidification, etc. When using a method such as nitrogen blanket, the cost of the nitrogen generator must also be considered. Table 1 outlines the basic costs involved with traditional layup methods, compared to similar VCI systems. For example, if we were to consider protecting the internals of a steam boiler system with dimensions of 20' x 20' x 10' (6.1mx6.1mx3.05m), the associated costs for preservation would be as follows:

Table 1
Cost Comparison of Preservation Methods on 20ftx20ftx10ft (6.1mx6.1mx3.05m) Vessel (Internal)

Product	Material Cost	Equipment Cost	Total Cost
Wax Based Coating	$120 (7)	$150-950 (8, 9)	$270-1070
VCI Liquid (Internal)	$75	$150-650	$225-725
Nitrogen Blanket	N/A	$5000-20,000+	$5000-20,000+
Desiccant	$0.31/cubic foot	None	$1240

Material costs were calculated based on product cost combined with recommended application/dosage rate. The cost of steam boiler repairs due to corrosion can be in the order of $50,000 to over $1m, plus cost of time off hire.[11] By utilizing a VCI system of liquid, this steam boiler system can be preserved for $725, which includes the cost of material, labor, and all equipment needed thus savings thousands of dollars.

	Post-manufacturing/shipping	Precommissioning
HRSG Manufacturer A	Pre-clean tubes of mill scale. Use proprietary techniques, desiccants, VCIs, and nitrogen blankets following shop hydro and during shipping.	Requires degreasing; chemical cleaning is optional, at owners discretion.
EPC A	Works with HRSG manufacture to keep tubes as clean as possible.	Requires high-velocity flush and one-step chemical cleaning (EDTA)
EPC B	Adds VCI during and following shop hydro.	Requires high-pressure washing of feed water and steam piping and degreasing of HRSG.
Owner A	Cleans HRSG tubes prior to assembly. Adds VCI once tubes are on site.	Does not flush, degrease, or chemically clean HRSG tubes. Unit put in service as is.
EPC C	Insists that tubes contain no oils from manufacturing. Requires that tubes be drained or that VCIs be dissolved in shop hydro water.	Insists on hydrolazing feed water and steam piping, clean erecting practices, high velocity flush. May also insist on chemical cleaning (citric) or degreasing.

Figure 2: Sampling of Industry Corrosion-Prevention Methods [10]

When considering the cost of a system, setup and removal cost must also be considered. VCI products can be flushed or sprayed with water, in the case of VCI liquids. Traditional methods may require harmful solvents and/or time-consuming procedures for removal and disposal. Limitations and concerns associated with using dehumidification systems are the relatively high cost of equipment, energy usage/cost, labor, maintenance of system, and dehumidification systems only protect the assets direct flow path and not the crevices or other void pockets not within the equipment's flow path.

Businesses spend $170 billion a year on costs associated with occupational injuries and illnesses.[12] Limitations and concerns associated with using nitrogen blankets require continuous supply of nitrogen making it a relatively costly process as well as the labor required to monitor and in the event of a leak, the conditions for corrosion would again be present. In addition, nitrogen being an asphyxiating agent the safety concerns related to using nitrogen such as failure to detect an oxygen deficient atmosphere in and around confined spaces, mistakenly using nitrogen instead of breathing air, and inadequately preparing for rescue for units/vessels that have been under nitrogen purge.

Real World Analysis

Liquid VCI preservation systems have been successfully used around the world in heavy industrial applications, on boilers, HRSG, generators, turbines, and other various pieces of equipment. The below Figures 3-5, highlight the application of a liquid VCI for a 53.0 megawatts power station located in a remote cold climate area that shutting down the steam turbine, boiler system, and associated pipelines for three (3) years. Approximate 1000 sq. ft. of internal carbon steel piping and vessels were located inside the facility and 15,000 sq. ft of carbon steel ducting and pipeline ran outside in an extreme cold environment with liquid VCI applications being successful in all environments.

Figure 3: Steam Drum of Boiler System Liquid VCI Application

Figure4: Pipeline Preservation using Liquid VCI

Figure 5. Steam System and Associated Piping

CONCLUSIONS

For 75 years, volatile corrosion inhibitors have successfully been applied into preservation applications worldwide. VCI fogging liquids have played a vital role providing protection both in the contact and vapor phases, as shown in NACE[1] TM0208-2008. Liquid VCIs have been successfully implemented in preservation of boiler systems, turbines, pumps, storage tanks, HRSG systems, generators, and piping systems with effective results lasting three to five years, with no corrosion noted.

VCI products provide an environmentally friendly cost effective means to achieve 24 months protection with products, which normally do not need to be removed prior to system startup. Periodic inspection is not required to assure that protection is in place and effective, no power source needed, and no recharging stations to replenish the inhibitor. These features eliminate the need for long-term lease or purchase of expensive equipment such as nitrogen and nitrogen charging systems, dehumidification systems, power supply nor individuals monitoring on a periodic basis.

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