# Evaluating Efficacy of Volatile Corrosion Inhibitors vs. Traditional Methods for Preservation of Industrial Equipment and Operational Spare Parts

ERIC UUTALA, CLIFF CRACAUER, AND BORIS A. MIKSIC, FNACE, *Cortec Corp. , St. Paul, Minnesota*

*Corrosion protection of industrial equipment and spare parts during mothballing and deep storage is an ongoing issue worldwide. Many factors must be considered when determining best practice for asset preservation. Length of time, type of equipment, accessibility, preventative maintenance schedule, and environmental and storage conditions have the greatest influence, while other conditions may also need to be considered. Traditional preservation methods such as nitrogen blanketing, desiccation, or heavy, wax-based surface-applied coatings can be costly to implement and maintain, and can become even more costly if they fail. Incorporation of volatile corrosion inhibitor (VCI) systems is an effective method to replace traditional preservation programs. These systems are often more cost effective to implement, have little to no maintenance cost, and have less failures in long-term preservation programs. In this article, VCI systems are explored in both laboratory and real world settings, compared to traditional systems and costs of each are compared.*

**Extensive research has been done on the** topic of mothballing and layup procedures using volatile corrosion inhibitors (VCIs).[1] Effective preservation of industrial equipment and operational spare parts requires many considerations. These considerations follow.

## Length of Protection

Short preservation times can mean high protection costs. Often, this leads to an approach where no VCI or other traditional methods of protection are used, because the upfront cost of preservation is perceived to be too high.

Conversely, long-term protection leads to low cost of protection. In this case, while clients will see the value in preservation, they struggle to determine the best method. Decisions are not always made based on the technical validity of the method, but rather convenience of application and/or inspection. Examples would include the use of humidity indicator cards or coupons to determine the presence or absence of corrosion protection within a package.

## Accessibility

Storage in remote areas (jungle, undeveloped locations) creates challenges in corrosion monitoring and replenishing protection. Equipment design can create further challenges related to accessing some of the internal spaces and other critical areas that require protection.

## Type of Equipment and Replacement Value

Value of equipment can be critical. However, the more important factor is replacement lead time and/or amount of time to rework equipment that is corroded. Unique or specially designed equipment often have long lead times if a replacement is required. This can lead to downtime at a plant, which can be orders of magnitude more costly than the equipment itself. Therefore, the cost of protection and preservation is irrelevant compared to the value of protecting the asset and the work time it provides.

Steam turbines, for example, are subject to regular, short-term down time for maintenance. In this time, corrosion can occur on ASTM A470[2] steel blades and discs. Specifically, these surfaces are subject to stress corrosion cracking (SCC), crevice corrosion, and hydrogen embrittlement. VCI liquids have been tested as effective corrosion preventives in this application.[3]

## Preventive Maintenance Schedule

Equipment and spare parts may have a regular preventive maintenance schedule, with weekly, monthly, or yearly inspections. Or, they have no scheduled inspection after the preservation process. This can have a significant impact on the preservation system used on a specific piece of equipment.

## Environmental and Storage Conditions

Arguably, this is the most important factor to consider in any preservation job. Material selection will vary greatly depending on the conditions in which the equipment will be stored, ranging from tropical coastal conditions to climate-controlled warehouses.

## Costs of VCI Protection Methods vs. Traditional Layup Methods

The total cost of preservation can be determined based on the specific method chosen. When using a method such as a nitrogen blanket, the cost of the nitrogen generator must also be considered. With a heavy-duty wax-based coating, removal time must be considered. Table 1 outlines the basic costs involved with traditional layup methods, compared to similar VCI systems.

The same costs would apply to protecting the internals of a piece of equipment, such as a pressure vessel (Table 2). However, a secondary VCI liquid can be used specifically for void space protection.

Material costs were calculated based on product cost combined with recommended application/dosage rate. Utilizing a VCI system of liquid and shrink film (250 µm), this piece of equipment can be preserved for $1,000, which includes the cost of material and all equipment needed.

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, or simply removed, in the case of VCI shrink film. Traditional methods may require harmful solvents and/or time-consuming procedures for removal and disposal. Nitrogen blanketing often requires hours of monitored leak testing prior to final purge.

## Experimental Procedure

The efficacy of VCI technology for corrosion protection of industrial equipment and spare parts during layup has been confirmed via multiple laboratory test methods, as well as real life applications (Figure 1).

**TABLE 1. COST COMPARISON OF PRESERVATION METHODS ON 20 BY 20 BY 10 FT (6.1 BY 6.1 BY 3.05 M) PIECE OF EQUIPMENT (EXTERNAL)**

| Product | Material Cost | Equipment Cost | Total Cost |
|---|---|---|---|
| Wax-based coating | $120[4] | $150 to $950[5-6] | $270 to $1,070 |
| VCI Liquid A | $5 | $150 to $950 | $155 to $955 |
| MIL-PRF-131[7] barrier film | $0.18/ft$^2$ (0.017/m$^2$)[8] | $5,000 to $6,500[9-11] | $5,180 to $6,680 |
| VCI shrink film (250 µm) | $0.08/ft$^2$ ($0.0074 m$^2$) | $650[12] | $730 |
| Nitrogen blanket | N/A | $5,000 to $20,000+ | $5,000 to $20,000+ |
| Desiccant | $0.31/ft$^3$ ($0.0088 m$^3$) | None | $1,240 |

**TABLE 2. COST COMPARISON OF PRESERVATION METHODS ON 20 BY 20 BY 10 FT VESSEL (INTERNAL)**

| Product | Material Cost | Equipment Cost | Total Cost |
|---|---|---|---|
| Wax-based coating | $120 | $150 to $950 | $270 to $1,070 |
| VCI Liquid B (internal) | $540 | $150 to $950 | $690 to $1,090 |
| Nitrogen blanket | N/A | $5,000 to $20,000+ | $5,000 to $20,000+ |
| Desiccant | $0.31/ft$^3$ ($0.0088 m$^3$) | None | $1,240 |

**FIGURE 1** Fully preserved military equipment using an integrated VCI system.

**FIGURE 2** VIA test setup with VCI film.

### *Laboratory Testing—Vapor-Inhibiting Ability (VIA) Method*

NACE TM0208-2008[13] was designed to determine the vapor-inhibiting ability of VCI products. In this test, carbon steel plugs are polished with sandpaper, cleaned with methanol, and then placed within a jar apparatus. VCI packaging is hung from the underside of the jar, ensuring that the VCI does not contact the steel plugs (Figure 2). The jar is sealed and allowed to sit in ambient laboratory conditions for 20 h. At this point, a glycerin and water solution is introduced, and humidity is created. The jars are allowed to sit for 2 h and are then placed in an oven set at 40 ± 3 °C for 2 h. The jars are then opened, and the steel plugs are visually inspected (Figures 3 and 4).

The NACE test method was modified as follows: first, steel plugs were cleaned with an ambient temperature methanol dip, as opposed to a 60-s boiling methanol immersion. Further, the plugs were hand dried with a lint-free wipe, as opposed to a heat gun or hair drier, per TM0208.

This type of test is especially relevant for VCI materials that will be used in mothballing and layup applications, since many of them will never be in direct contact with the metal surfaces they are meant to protect. If the products are unable to pass this test, they will likely fail in preservation applications as well. VCI shrink films are regularly run to a modified version of NACE TM0208-2008 to ensure their efficacy.

### *Laboratory Testing—VCI Packaging vs. Barrier Film for 15-Year Storage*

In preparation for a 15-year build ahead storage program, automotive transmission components were wrapped in one of the fol-

**FIGURE 3** VIA test results with VCI shrink film. Control plug is on the far right.

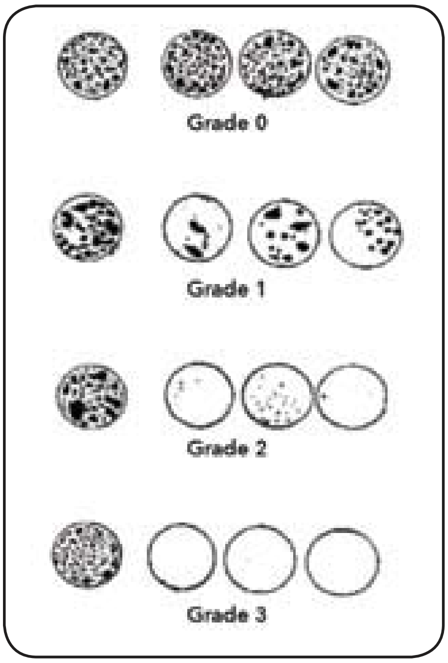

**FIGURE 4** VIA test grades.

**FIGURE 5** Automotive transmission component after 16 weeks in modified ASTM D1748 testing, wrapped in VCI film.

**FIGURE 6** VCI aerosol used to protect combat vehicle reconnaissance (CVR) wheels. VCI additives were also used in the fuel, coolant, engine, gearbox, drive, and brake systems.

**FIGURE 7** CVR wrapped in VCI shrink film, in place for final preservation.

lowing: a single-layer VCI film, a multi-layer VCI film, or a standard foil barrier film. After being wrapped, components were exposed to modified ASTM D1748[14] conditions. Test conditions were 49 °C (120 °F) and constant condensing humidity, per ASTM D1748. However, the test was much larger than that of the standard, in order to allow the number and size of components to be tested. As such, the wrapped components were not in constant rotation, per the standard. Parts were removed, unwrapped, visually inspected, and photographed on a four-week schedule, for a total of 20 weeks (Figure 5).

### *Real World Analysis*

VCI preservation systems have been used in military and industrial applications worldwide for over 60 years. More recently, these projects have focused on vehicle and heavy equipment preservation, which addresses multiple systems, starting with grease points along the axle, moving to all relevant fluid reservoirs (oil, fuel, coolant, etc.), and finishing with a VCI shrink wrap around the entire piece. The goal is to leave a vehicle or piece of equipment that is completely preserved, but ultimately ready for use at a moment's notice.

## Results and Discussion

### *VIA Test*

VCI films (both shrink and standard) are regularly run through VIA testing to ensure that they can provide effective corrosion protection while not in contact with the metal surface. Figure 2 shows the test setup. Figure 3 represents typical VIA results for an effective VCI film.

### *Laboratory Testing—VCI Packaging vs. Barrier Film for 15-Year Storage*

After 20 weeks of modified ASTM D1748 testing, the most effective corrosion protection system was with a multi-layer VCI packaging system.[15] This system was implemented for the 15-year warehouse storage program, and no corrosion claims were made during that time.

### *Real World Analysis*

VCI preservation systems have been successfully used around the world in military and heavy industrial applications, on vehicles, various pieces of equipment, and critical operational spare parts. Storage conditions have ranged from indoors (temperature-controlled warehouses) to outdoor, tropical conditions. Applications have been successful in all of these areas. Figures 6 through 13 show examples of VCI preservation systems being used on a variety of equipment.

## Conclusions

For more than 60 years, VCIs have been effectively implemented into preservation applications worldwide. VCI films are an integral part of these systems, and they will provide protection both in contact and vapor phase, as shown in NACE TM0208-2008. Multi-layer VCI packaging systems have been successfully implemented in preservation of operational parts for programs lasting over 10 years, with no corrosion claims.

In the case of larger pieces of equipment, more diverse VCI systems have been effectively implemented for preservation. These types of systems have been used for the United States Armed Forces and the United Kingdom Ministry of Defense,[16] along with many manufacturers of heavy industrial equipment.

Additionally, VCI systems provide a preservation method that is cost neutral at worst, and in many cases provide a cost benefit compared to traditional chemical methods. This does not take into account the labor savings, performance capability, or disposal costs, which can be difficult to quantify when speaking in generalities. When compared to nitrogen or dehumidification systems, VCI preservation programs provide a clear cost and performance benefit. Additionally, they can be implemented in virtually any environment, as they do not require access to power or other utilities needed to provide continuous protection and monitoring over an extended period of time. VCIs provide an effective layup and mothballing system that traditional methods cannot meet from a cost or performance standpoint. Equipment costs are minimal for application, as are costs associated with maintenance, cleanup, and disposal of waste materials.

**FIGURE 8** United States Air Force cargo loader, preserved with VCI shrink film.

**FIGURE 9** Three United States Air Force cargo loaders, preserved with VCI shrink film.

**FIGURE 10** Gas turbine shells, prior to preservation.

**FIGURE 11** Gas turbine shells, after preservation with VCI shrink film.

**FIGURE 12** Rotor being cleaned prior to preservation.

**FIGURE 13** VCI shrink film being applied to rotor.

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**ERIC UUTALA** is the technical service manager at Cortec Corp., 4119 White Bear Pkwy., St. Paul, MN 55110, e-mail: euutala@cortecvci.com. After graduating from the University of Minnesota-Duluth, he has been working in Cortec's Technical Service Dept. since 2006.

**CLIFF CRACAUER** is vice president of Sales at Cortec Corp., e-mail cliff@cortecvci.com. He has 16 years of experience at the company and previously held the positions of technical service engineer and technical sales manager. He has a B.S. degree in chemistry from the University of Minnesota's Institute of Technology, holds two patents, and has published nine papers. He is a six-year member of NACE International.

**BORIS A. MIKSIC, FNACE,** is president and chief executive of Cortec Corp. He has served in this capacity for 38 years. Cortec is a world leader in the manufacture of corrosion inhibitors in several industries, including modern plastic products. Miksic holds more than 43 U.S. and foreign patents and patent applications and has presented papers throughout the world. He received the NACE International F.N. Speller Award for longtime contributions to corrosion engineering. A NACE Fellow, he has been a NACE member for more than 40 years. MP