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MP

A Supplement to

MATERIALS PERFORMANCE

CORROSION PREVENTION AND CONTROL WORLDWIDE

FOCUS

VCIs EXPAND ARSENAL IN THE WAR AGAINST CORROSION

Preserving U.S. Air Force Vehicles

Corrosion Inhibitor Use on the Trans Alaska Pipeline

Water Treatment Applications

Storage Tank Protection

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CORROSION PREVENTION AND CONTROL WORLDWIDE

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New VCI Technologies Fight Corrosion, Protect Environment

Where reducing the total cost of asset preservation is the primary measure of success for a corrosion control endeavor, few corrosion-fighting tools are as versatile and cost-effective as volatile corrosion inhibitors (VCIs).

VCIs and the related vapor-phase corrosion inhibitors (VpCIs) are now being used to prevent corrosion in everything from pipelines to military vehicles and electronics to cooling towers. Application methods are equally diverse, ranging from coatings to passive vapor emitters.

VCI performance is driven by the ability to alter the environment where corrosion occurs. They can be designed to form protective barriers on internal or external surfaces or alter the corrosive properties of an enclosed vapor space. Migrating corrosion inhibitors (MCIs) can even diffuse into concrete to help protect embedded reinforcing steel.

The articles that follow illustrate VCI and VpCI performance in a wide range of industries and applications. One article highlights how VpCIs are used to reduce corrosion in low-flow areas and other components of the Trans Alaska Pipeline. Another shows how the U.S. Air Force is using them to fight corrosion where long-term storage and rapid equipment mobilization are mandatory.

The chemical processing industry is using VCIs and VpCIs to limit corrosion in condensers, cooling towers, and boilers during shutdown or standby, and a related article summarizes how they perform in those environments. Other articles describe applications to packaging systems to prevent corrosion of metal components during shipping and storage, to electronics, to tank bottoms, and to coating systems.

Whether asset preservation is a matter of national security or job security, VCI technology is a powerful weapon for fighting corrosion.

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Preservation of U.S. Air Force Vehicles and Equipment

ANNA M. VIGNETTI.

The U.S. Air Force (USAF) initiated an Air Staff Level Test Program to protect military vehicles and air ground support equipment. Corrosion damages millions of dollars of valuable assets every year, jeopardizing war readiness. Many different preservation products have been evaluated and utilized over the years. A recent initiative evaluated vapor corrosion inhibitor (VpCI) products and systems in deep storage and preservation for war readiness materials. This article discusses USAF corrosion control requirements and its evaluation of VpCI systems.

In recent years, armed forces worldwide have become more aggressive in preventing corrosion. Corrosion problems in the military date back to ancient times, but recognizing prevention as a necessary part of maintenance, operations, and storage began as recently as World War II.[1] Many different preservation products and methods have been evaluated and utilized[2] over the years. Currently, millions of research dollars are spent each year in the war against corrosion. Losing valuable assets is a major concern; however, war readiness and the prevention of catastrophic failure are paramount in the overall scope of corrosion prevention.

The U.S. Air Force (USAF), like many other U.S. military branches, has taken bold steps to objectively evaluate different methods. The most recent initiative evaluated vapor corrosion inhibitor (VpCI) products and systems in deep storage[3] and preservation for war readiness materials. VpCIs are chemical compounds that have significant vapor pressures that allow molecules to vaporize and then adsorb on metallic surfaces.

This article details the objective, parameters, environment, benefits, and results of the USAF's VpCI test. Evaluating VpCI technology as a total system of protection was the focus of this test program. The USAF had adopted a chemical preservation storage program, but it was subsequently delayed for this evaluation.

Experimental Procedures

TEST OBJECTIVES

The evaluation was initiated to validate and compare deep storage preservation systems for vehicle and air-ground support equipment with a commonly used chemical preservation technology and a newer VpCI system. VpCI performance on different metals in industrial and marine atmospheres was studied and analyzed experimentally to show corrosion rates (Table 1).[4] VpCI products have been used for 5 decades, and newer VpCI technologies have since been developed. This test program evaluated a system/solution approach.

The test defined the expected life of a deep storage/preservation system at 3 to 5 years, with minimal or no upkeep. It considered the reapplication of current chemical preservation as well as requirements for exercising, time, and labor. The reduction of forces makes reapplying the products and exercising the vehicle and equipment assets difficult and costly.

The next objective was to attain zero equipment deterioration. The desired goal was to achieve a sustained 90% overall vehicle in commission (VIC) success rate in corrosion protection and mechanical functions. Minimal mechanical degradation was a critical factor in the test. Again, as a result of less manpower, the decrease of mechanical problems at breakout is critical and necessary in a deep storage program.

TEST PARAMETERS

The USAF set a number of key parameters for the program. Preparation for the actual test began with identifying the vehicles and equipment to be preserved. USAF teams selected and issued orders to prepare the selected assets. The test length was predetermined for a term of 1 year.

TABLE 1

VCI PERFORMANCE IN INDUSTRIAL AND MARINE ATMOSPHERES

Metal		Corrosion Rates (mils/y)	
		No Inhibitor	VpCI Protected
Aluminum (1,000, 3,000, 5,000, 6,000 series)		0.3	<0.25
Mild steel		21.8	<0.13
HSLA (high-strength, low-alloy steel)		1.2	0.08
Naval brass		0.2[A]	0.03
Titanium		0.0[B]	0.0[B]
Stainless steels:	Type 410	0.01[C]	0.01[D]
	Type 304	<0.1[E]	0.01[F]
	Types 301, 316, 321	0.0[G]	0.0[G]
Copper		0.22[E]	0.01[F]

Notes:
[A]Dezincification, [B]Immune to attack; no pitting or weight loss observed, [C]Pitting,
[D]Pitting reduced, [E]Staining, [F]No Staining, [G]Free from pitting and weight loss.

Preparation

The USAF team requested that the individual sites prepare the assets to "excellent" working and physical condition. The VpCI manufacturer then assessed and calculated product needs based on vehicle and equipment specifications. The company provided training procedures, materials, equipment, and personnel to assist and train military personnel in the application of the VpCI products. Contractor and military personnel were deployed to prepare the equipment and perform the actual preservation. Each asset was thoroughly inspected and repaired prior to the procedure.

Test Sites

Five locations were chosen to fairly evaluate different climatic zones and atmospheric conditions. Guam was chosen because of its extreme climates and severe corrosion conditions. The trade winds and high ultraviolet (UV) light exposure make this location suitable for the tropical environment. Two locations in Korea, one located centrally and the other near the coast, would give a good evaluation of the four seasons in two different environments. The climate varies from very hot and humid to extremely cold with a great deal of precipitation. Last, two locations in Oman round out the categories of climatic conditions. The first offers desert extremes with high UV. The second, with hot, humid conditions, is found on the Persian Gulf coast. During testing, the assets were located in climate-controlled and bare sheds as well as outside in all climates and atmospheres.

Identifying Assets

Assets—personnel vehicles as well as equipment for tactical, road building, and air-ground functions—comprised the widest possible range of vehicles and equipment for a fair evaluation. The air-ground equipment (AGE) included bomb lifts, compressors, trailers, and generator sets. Different storage scenarios were made for the same asset if more than one was used in the test.

Each of the five locations was chosen to preserve a total of 180 vehicles. Two locations—Guam and Osan, Korea—were chosen to evaluate AGE. At the time of preservation, asset preparation varied from fair to excellent. Lessons learned from one location to the next helped in the preparation but did not affect the outcome of the final results. A total of 119 vehicles and 60 pieces of AGE were used in the final preservation. Ten medium-sized vehicles were chosen for the chemical preservation process.

Products

The products used compatible technology to provide a system solution. Many of these products are already being used successfully by armed

TABLE 2

LIST OF MILITARY SPECIFICATIONS

No.	Inhibitors	Description
1	MIL-PFR-87937C	Cleaning compound, aerospace equipment
2	MIL-C-16173E	Corrosion preventive compound, solvent cutback, cold application
3	MIL-P-46002B	Lubricating oil, contact and volatile corrosion inhibited
4	MIL-C-83933A	Corrosion preventive compound, cold application
5	MIL-C-81309E	Corrosion preventive compound, water displacing, ultra thin film
6	MIL-I-22110C	Inhibitors, corrosion, volatile, crystalline powder
7	MIL-PRF-81705D	Barrier materials, flexible, electrostatic protective, heat-sealable
8	MIL-PRF-22019D	Barrier materials, transparent, flexible, sealable, VpCI-treated bags, transparent, flexible, heat seal, VpCI-treated
9	MIL-B-40028B	Bags, barrier with VpCI-treated liner

forces worldwide. Military specification numbers (Table 2), National Stock Numbers (NSN), Qualified Product Listings (QPL), and NATO numbers are already in place for most of the products.

From the start, surface preparation entailed cleaning/degreasing and removing rust from products that had been modified with VpCI additives to enhance corrosion prevention. VpCI-emitting products were used for electronic compartments and miscellaneous enclosures such as large void spaces and vehicle cabs. Temporary and permanent coatings were used to coat undercarriages. Clear, permanent coatings provided overall coverage for selected assets. Bare metal surfaces on moving parts such as forklift chains and hydraulic cylinders were lubricated. Fuel coolant, oil, and hydraulic additives complemented the internal systems. Finally, four types of covers were used that were custom-fabricated to contain VpCI additive technology.

Application Procedure

The application followed a step-by-step process. Throughout application, up to five individuals worked on a single asset. Multiple procedures were performed simultaneously, allowing for optimum use of time and personnel. Normal maintenance directives included military procedures for repairing and preparing assets prior to preservation (Figure 1).

Step 1: Prepare the vehicle or equipment according to the state or condition desired at breakout time. Complete a thorough inspection, noting discrepancies, condition, and record of vehicle condition. Take pictures showing the condition and discrepancies.

Step 2: Remove rust with a liquid or wipe-type product containing VpCI additives.

Step 3: Wash down with a VpCI cleaning product (Table 2, No. 1). Remove heavy oil or grease with a VpCI wipe. Do not rinse. Allow it to partially air dry and wipe with a dry cloth.

Step 4: Apply a permanent VpCI water base, clear-coating for selected assets. Apply one coat at a 2-mil (50-µm) wet film thickness. For severe corrosion conditions, where vehicles will not be stored inside or with a cover, wait 30 min to 1 h and apply a second coat at a 2-mil thickness.

FIGURE 1

60K cargo loader with VpCI military shrink wrap.

Step 5: Apply a VpCI lubrication coating to all working and moving parts as well as bare metal such as hydraulic cylinders. Apply a paraffin-based VpCI coating to rusted areas beneath vehicles or equipment (Table 2, Nos. 2 and 4).

Step 6: Lower the liquid level of coolants, hydraulic oil, and regular oils (Table 2, No. 3) to the required capacity for the additives. Fill fluid reservoirs with the required VpCI additive product. Required product calculations are made prior to application. Charts specifying capacities and measured fluids to be added were also provided.

Step 7: Apply a VpCI-modified lubricating grease to all areas normally greased (Table 2, No. 4), including zirconium fittings.

Step 8: Apply VpCI electronic spray (Table 2, No. 5) to all electronic/electrical connections, control panels, wiring, items under the hood and dash, battery boxes, etc. Apply VpCI-emitting devices (Table 2, No. 6) to storage and battery boxes, electronic/electrical enclosures, and under the dashboards. Place VpCI foam pads in large void spaces and in cabs (Table 2, No. 7).

Step 9: Apply VpCI protective covers. Four covers were selected: VpCI polyethylene shrink film, VpCI reinforced films with and without a soft interior lining, and a VpCI high-UV reinforced cover with a soft interior lining. Table 2 (Nos. 8 and 9) gives the specifications for these products.

Steps 5 through 8 may be performed simultaneously for efficiency. The process was timed from start to finish.

Test Results

This evaluation concurs with other storage tests. It considers VpCI usage by other branches of the military as well as industry.

MONITORING

Prior to storage, military and contract personnel thoroughly inspected and extensively photographed records of the assets. A limited number of assets were evaluated at 6 months for the Pacific Air Forces (PACAF) region and at 9 months for the USAF, U.S. Central Command (CENTAF) locations. Results of corrosion protection at this point were impressive. Although there was high condensation and excessive amounts of water, they achieved more than 90% corrosion protection.

Following storage, the vehicles were placed in areas that would provide heavy use for a 90-day period. The goal of zero defects was accomplished, and mechanical failures were not reported as a result of the VpCI protection system.

In September 2000, after 12 months of preservation, the PACAF assets were depreserved. Photographs and extensive evaluations recorded the assets' condition. They show that corrosion protection and mechanical soundness exceeded the 90% VIC rate. Removing the covers took no longer than 4 min, but starting the vehicles took the bulk of the recorded time in the depreservation procedure. It was no longer than replacing or jump-starting a dead battery. Removing VpCI products other than the covers was unnecessary; remaining products will continue to protect the assets. Immediate war readiness was accomplished.

APPLYING CHEMICAL PRESERVATION

Ten vehicles were designated for traditional chemical preservation. Lengthy application and removal times make this a costly alternative. Applying the exterior and interior products was a very detailed process. The assets were stored indoors. Application time per vehicle was up to 5 days—practically pulling the vehicles apart made this very time-consuming and labor-intensive. Breakout times ranged from 5.5 to 6 h per vehicle. Using flammable solvents made removal hazardous and cumbersome.

The USAF and other military branches have taken the initiative to replace hazardous products and cumbersome work practices.

VpCI PRODUCT APPLICATION

This test analyzed VpCI system application in terms of vehicle type, product cost, and required labor/man-hours. Table 3 presents a brief analysis. Additional time and labor were not required for the application process. The average breakout time was 18 min per vehicle—this included the removal of any cover used and the actual vehicle start-up. Regardless of asset size, only a few minutes were needed for cover removal. It was not necessary to remove other VpCI product. The assets were ready for immediate utilization or war readiness. All vehicles and equipment were placed in high-usage areas to evaluate the product's effects, if any, on asset operation.

TABLE 3

Vehicle	Application in Man-Hours/Unit	VpCI Product Cost (U.S. Dollars)/Unit
Average of 120 vehicles	4.14 h	$338
HMMVW	2.69 h	$160
40K air cargo loader	7.5 h	$795

Notes: Many other vehicle types were included to illustrate the differences in cost.
Application included the entire process from initial cleaning and coating to the final step.

VpCI SYSTEM BENEFITS

The benefits of VpCI systems in deep storage and preservation were quickly noted throughout the application process and upon completion of the test. One major advantage is the ease with which military personnel can become proficient in applying VpCI products. Another is the efficiency of application and removal—an economic benefit. Although product cost was competitive to that of existing products, it was not the most critical factor in the evaluation.

It was not necessary to operate the equipment during the test. Of the few malfunctions identified after breakout, none were caused by the VpCI preservation system. This in itself is critical because it decreased the costs of parts and labor. Further analysis will determine the overall savings.

The reduction in breakout time compared to that of other preservation programs was also significant. Interest in this system continues to grow, and a final executive report will be presented to the Air Staff at the Pentagon.

The USAF and other military branches have taken the initiative to replace hazardous products and cumbersome work practices.

Conclusion

This VpCI technology is revolutionary in terms of vehicle and equipment storage. It has proven itself commercially and industrially, and the savings outweigh the costs and any possible risks involved in testing.

A cost analysis comparing traditional and VpCI processes determined the VpCI products provide superior corrosion protection even in extreme atmospheric conditions. The reduction of manpower stands out because it revolutionizes asset protection. The entire VpCI storage process/system approach is simple and efficient. After only 1 day of training, the USAF team was well-versed in the technique.

After operating the vehicles in the 90 days following final depreservation, the USAF concluded the VpCI process and materials would be a great asset to the USAF War Readiness Materials vehicle storage program. The time required to prepare and breakout the vehicles and equipment and the system's level of corrosion protection would enhance war-fighting capabilities.

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Use of Corrosion Inhibitors on the Trans Alaska Pipeline

ERNEST W. KLECHKA

Inhibitors are used on the Trans Alaska Pipeline to protect low-flow areas, dead legs, the annular space in road casings, and contingency equipment. Low-flow areas and dead legs are protected with a water-soluble corrosion and scale inhibitor, a mild biocide, and an oxygen scavenger. A vapor phase corrosion inhibitor (VpCI) is used to protect the annular space in road crossings. Contingency equipment is protected during long-term storage with either a VpCI or an oil-based film.

Corrosion inhibitors are used in several operational areas of the Trans Alaska Pipeline. During normal pipeline operation, warm crude oil with small amounts of salt and water travels through the pipeline. The salt and water can accumulate in areas of low flow such as bypass piping and future pump piping connections. If not controlled, corrosion can damage operating equipment and cause expensive and potentially disruptive repairs.

If left unprotected, the warm pipe in moist soil can corrode externally. Belowground sections of the pipeline are protected with coatings and cathodic protection (CP). Road casings may interfere with the CP system (Figure 1). Inhibitors are used to control corrosion inside the road casing.

Contingency equipment is stored in unheated warehouses or outdoors. Both vapor phase corrosion inhibitors (VpCIs) and inhibited oil films have proven useful in protecting contingency equipment.

Effects of Inhibitors

An inhibitor is a substance that, when added in small concentrations, decreases the effective corrosion rate. Inhibitors fall into four general categories based on mechanism and composition. These categories are 1) barrier layer formation, 2) neutralizing, 3) scavenging, and 4) other environmental modification.

BARRIER INHIBITORS

Barrier layer formation inhibitors form a layer on the corroding metal surface, modifying the surface to reduce the apparent corrosion rate. They represent the largest class of inhibitive substances.

Adsorption-type inhibitors are the most common barrier layer inhibitors. In general, these organic compounds are adsorbed and form a stable bond with the metal surface. The apparent corrosion rate decreases as surface adsorption is completed (Figure 2).

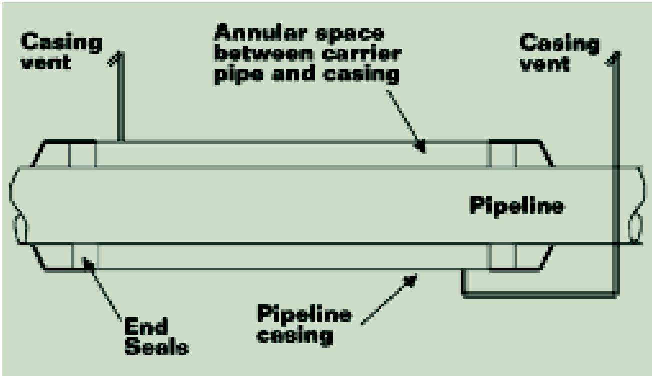
VpCIs are adsorption-type inhibitors with high passivating properties. These inhibitors form a stable bond with the metallic surface. Generally, they have a high vapor pressure that allows the material to migrate to distant metallic surfaces. Therefore, VpCIs require no direct contact with the metal surface to be protected.

Conversion inhibitors also form barrier layers. They passivate the metallic surface by developing an insoluble metal oxide on the surface. Typical examples of this type of inhibitor are organic phosphates and chromates.

NEUTRALIZING INHIBITORS

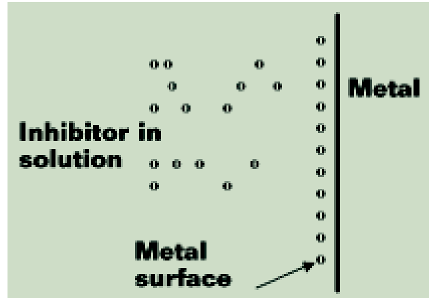
Neutralizing inhibitors reduce the hydrogen ion in the environment. Typical neutralizing inhibitors are amines,

FIGURE 1



Below ground road casing. Annular space between the casing and the carrier pipe can be protected with a VpCI or filled to mitigate corrosion in the annular space.

FIGURE 2



Adsorption-type inhibitors are a common form of barrier layer inhibitor.

ammonia (NH_3), and morpholine. These inhibitors are particularly effective in boiler water treatment and weak acid solutions but have not been widely used on pipelines.

SCAVENGING INHIBITORS

Scavenging inhibitors remove corrosive ions from solutions. Well-known scavenging inhibitors include hydrazine and sodium sulfite. These two inhibitors remove dissolved oxygen from treated boiler water.

Sodium sulfite reaction:

$$Na_2SO_3 + {}^1/_2\ O_2 = Na_2SO_4 \qquad (1)$$

Hydrazine reaction:

$$2\ (H_2NNH_2) + {}^1/_2\ O_2 = 2NH_3 + H_2O + N_2 \qquad (2)$$

Low Flow or Dead Legs

During pipeline operation, water accumulates in isolated piping and dead legs (non-operational piping installed for future expansion). As crude flows by isolated piping or dead legs, the small amount of salt and water present in crude oil accumulates in these areas. Because of the high salt concentration, corrosion can occur rapidly. If left unchecked, damage to the piping will occur.

A water-soluble corrosion inhibitor combined with a scale inhibitor, a biocide, and an oxygen scavenger, can prevent corrosion in the piping. These materials are a proprietary blend of organic polyphosphates, alkyl quaternary ammonium chloride ($[RNH_3]Cl$), and sulfite (M_2SO_3). This inhibitor can treat salt-water-carrying systems in the oil field. The organic polyphosphate forms a barrier to protect the pipe surface. Alkyl quaternary ammonium chloride RNH_3Cl and M_2SO_3 act as a biocide and an oxygen scavenger.

This inhibitor was diluted with water and injected directly into dead legs and future pump connections (Figure 3). Periodic testing of the inhibitor concentration was specified to assure continued protection.

Road Crossings and Casings

To protect the pipeline from mechanical damage, road casings were installed at all major road crossings. These casings were separated from the pipe with insulators, and the pipe ends were sealed with Link-Seals† (Figure 4). These seals are intended to keep water out of the casing and help provide electrical isolation for the pipeline from the casing. As the system ages, the effectiveness of these seals becomes more difficult to verify.

To prevent the corrosion inside the casing, several possible treatment methods were reviewed. These methods included 1) removing the casing, 2) filling the casing with a filler, and 3) introducing a VpCI.

Removing the casing is generally not cost-effective because it disrupts the road crossing and requires extensive excavation. Cutting to remove the casing also endangers the pipeline.

Casing fillers are generally mastic-, asphaltic-, or petrolatum-based. Normally, these materials thicken in cold weather and make application in arctic winter conditions very difficult. The cost of shipping large volumes of filler to Alaska makes this material relatively expensive.

VpCIs work in both the water and the vapor space and are available in concentrated powder form. The inhibitor can be mixed on-site for immediate application. When compared to casing removal or filler application, this material is relatively inexpensive.

† Trade name.

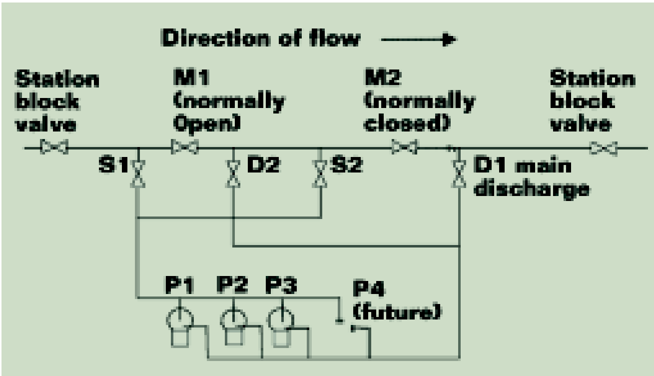
Applying VpCIs to Road Crossings

VpCIs were first applied through existing casing vent pipes. The inhibitor was measured and poured into the casing vent pipe, and a small rubber ball was inserted to act as a piston. The vent pipe was then pressurized with nitrogen to push the ball and the inhibitor into the road casing.

After several years, water samples were taken from several of the road casings. These samples were analyzed to determine how much inhibition remained. The level of inhibitor needed to protect the road crossing was set at 200 ppm. However, inhibitor remaining in some of the casings was as low as 2 to 3 ppm. At the same time, several other road casings showed inhibitor concentrations as high as 6,000 ppm.

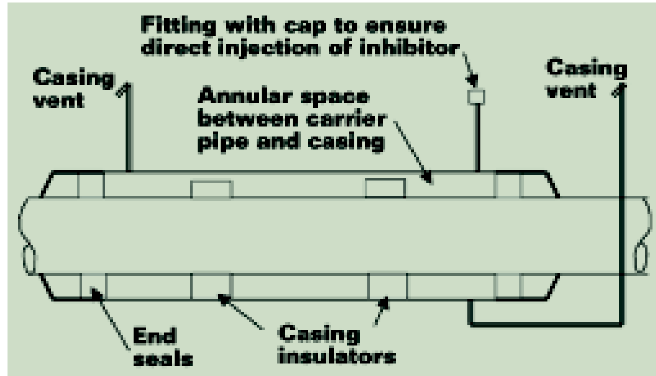
The apparent low level of inhibitor concentration in several of the road casings could be traced to problems encountered with the filling operation through the vent pipe. Many of these vent pipes are more than 300 ft (91 m)

FIGURE 3



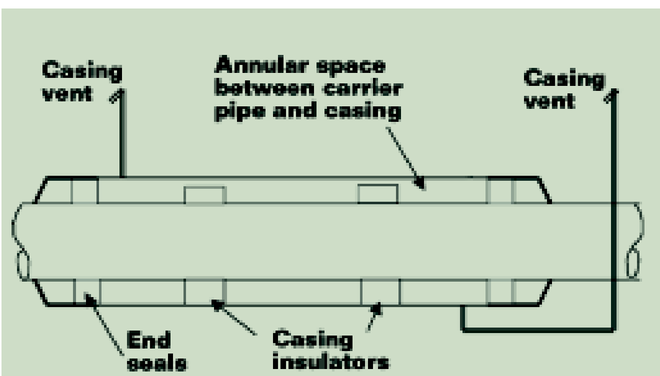
Dead legs and low flow area are injected with inhibitors to control internal corrosion. Dead legs include future mainline pump (P) 4 suction and discharge piping installed during construction of the pipeline. Low-flow piping includes the secondary discharge piping (D2) and the piping behind M2.

FIGURE 5



Road casing modifications to improve injection with inhibitor. To improve injection with inhibitor a new fitting was attached to the casing allowing direct injection of inhibitor.

FIGURE 4



End closures on road casings. Ends seals and insulators are intended to electrically isolate the road casing from the main pipeline.

long and have been subject to damage. Vent pipe blockage has occurred as a result of bending (caused by settling or traffic loads), mud infiltration, or rock slides.

A second application of inhibitor was necessary where low levels of inhibitor were found. To ensure direct inhibition of the road casing, the vent pipe was modified (Figure 5). Generally, the upper vent pipe was replaced with a vent pipe going directly from the casing to the surface. If this was not possible, a new vent pipe going directly to the surface was added. New inhibitor was poured directly into the casing. This modification provides direct access for testing and should result in more accurate tests.

Protecting Contingency Equipment

Contingency materials—large valves and other items that have long delivery times—are stored for ready access. In the past, large valves have been stored with an oil-based inhibitor coating on critical surfaces. In areas such as seats, the oil can be wiped off by the valve seating action; this removes the inhibitor, allowing the seat area to corrode in a manner similar to crevice corrosion. Valve gate pitting can occur in these locations.

Large valves are routinely hydrotested to ensure a leak-proof pressure-tested valve. To improve the valve's corrosion protection, the hydrotest water has been saturated with a VpCI. The hydrotest simultaneously pressure tests and inhibits the valve.

Valves used for draindowns, bypasses, and other temporary applications are cleaned, inspected, and inhibited with a powder VpCI before being returned to contingency storage. The powder form of the inhibitor quickly protects the valve from corrosion.

Conclusions

Corrosion inhibitors have improved the reliability and accessibility of the piping and contingency equipment. Dead legs are now protected and available should the need for a new pump arise. Corrosion of piping inside a road casing has been mitigated with minimal expense. Contingency equipment is available from storage with minimal maintenance and preparation.

Because of the low concentration of inhibitors in the dead legs, there has been no detectable effect on the crude oil. In addition, using biodegradable VpCIs in road crossing casings and contingency equipment has produced no adverse environmental effects. Finally, the most important consequence of using corrosion inhibitors on operating equipment has been a decreased corrosion rate.

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MCI® Protection of Concrete

DUBRAVKA BJEGOVIC AND BORIS MIKSIC, FNACE

Migrating corrosion inhibitors (MCIs) were developed to protect steel rebar from corrosion in concrete. They were designed to be incorporated as an admixture during concrete batching or used for surface impregnation of existing concrete structures. Two investigations are summarized. One examines the effectiveness of MCIs as a corrosion inhibitor for steel rebar when used as an admixture to fresh concrete. The other is a long-term study of MCI concrete impregnation that chronicles corrosion rates of rebar in concrete specimens. Based on data from each study, it was concluded that MCIs are compatible with concrete and effectively delay the onset of corrosion.

Reinforced concrete structures are usually durable in average environments. However, when exposed to variable environmental factors, such as carbonation and/or chloride attack, a structure's integrity and safety can easily be compromised. These attacks reduce the potential service life of a structure and increase maintenance costs. This problem has not been adequately addressed within the engineering community. Obvious design goals should be to enhance concrete's durability and performance and reduce maintenance costs. After years of concrete restoration analysis, civil engineers have concluded that even with relatively new projects, little or no effort has been made to significantly counteract the negative environmental impact on concrete. Improving concrete's reliability needs to be a top priority.

For years, there have been several different protection options. A wide range of corrosion inhibitors are available,[1-4] which can be divided into groups according to application and type of corrosion process (Figure 1). Most products are designed to protect either the concrete *or* the steel rebar (Figure 2).

New migrating corrosion inhibitor (MCI) technology is designed to protect both the concrete and the reinforcement steel. MCIs substantially decrease the corrosion rate of steel rebar embedded in concrete.

MCI Technology

MCIs are based on amino carboxylate chemistry. They are effective "mixed" cathodic and anodic corrosion inhibitors.[5-7] Under normal conditions these substances enhance the vapor pressure.[8-12] Increased pressure causes the inhibitor molecules to diffuse through the concrete. This diffusion process requires a period of time to migrate through the concrete's pores. Once the MCIs migrate to the rebar's surface, a monomolecular protective layer is formed. This suggests that the migratory inhibitors are physically adsorbed onto the metal surfaces.

MCIs can be incorporated as an admixture or can be used by surface impregnation of existing concrete structures. With surface impregnation, diffusion transports the MCIs even into the deeper concrete layers. They will delay and inhibit the onset of corrosion on steel rebar.[10-11]

MCI Admixture Study

MCIs were incorporated into several fresh concrete mix batches with various weight-to-concrete proportions. Two types of additives were prepared with two different MCI dosages, and a statistical analysis was performed (Table 1). The mix included a superplasticizer and an air-entraining agent. MCIs were found to be compatible with all additives used in concrete mixes.

They did not adversely affect any ingredients that were used in the concrete mix.

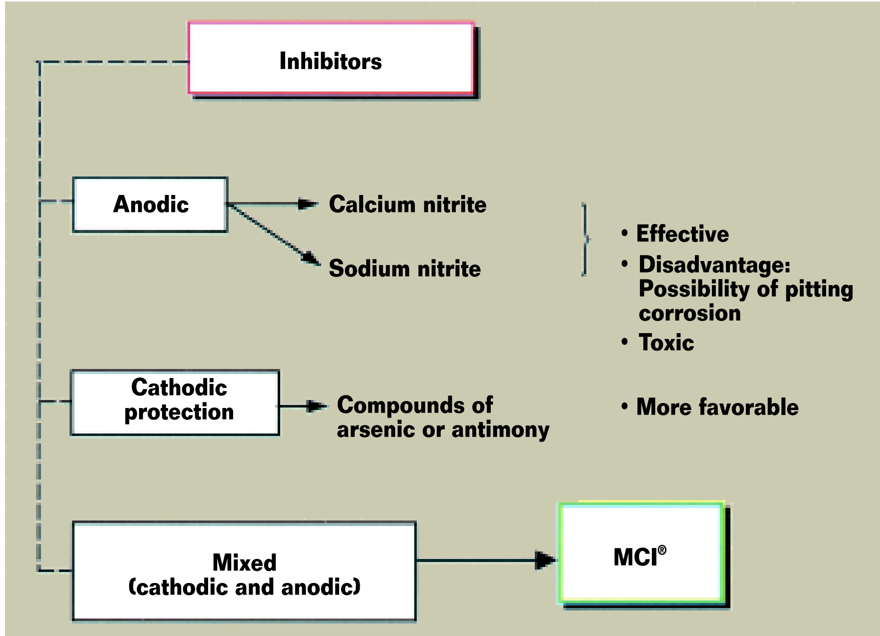
The experimental mix was prepared with 356 kg/m^3 of concrete (label PC 30z 45s) and included a natural fractionated aggregate that had a maximum granulation of 31.5 mm. The prepared mix was formed into similar-sized "block" specimens. The test parameters followed modified ASTM G 109[12] procedures.

These prepared specimens also included three 14-mm diameter bars inserted at two different levels of the concrete. One bar was at 3.0 cm from the specimen's surface, acting as an anode. The other two bars were connected in series, 2.5 cm apart and 11.5 cm from the concrete surface, as cathodes. A Plexiglas† "wall" was constructed around the top edge of the concrete block. This fluid containment area was used to create a pool. The pool was filled with a 3% sodium chloride (NaCl) water solution that was in direct contact with the specimen's surface. Contact time for each cycle was 4 consecutive days. After the NaCl/water solution was drained, the samples were placed in an environmental chamber for the next 3 days of the cycle. To speed up the drying process, the chamber was set at an elevated temperature of 60°C.

Next, a 100-Ω resistor was connected between the cathode and the anode bars. The voltage between the anode and the cathode was measured after each weekly cycle, and from these readings the current was calculated and noted. The study was continued until the specimen's current achieved a 10-µA deviation, or for 1 year, whichever was first. Concurrently, the potential difference between the anode and the reference electrode (copper/copper sulfate [Cu/$CuSO_4$]) was also measured according to ASTM C 876.[13] Figures 3 and 4 show the results regarding potential differences.

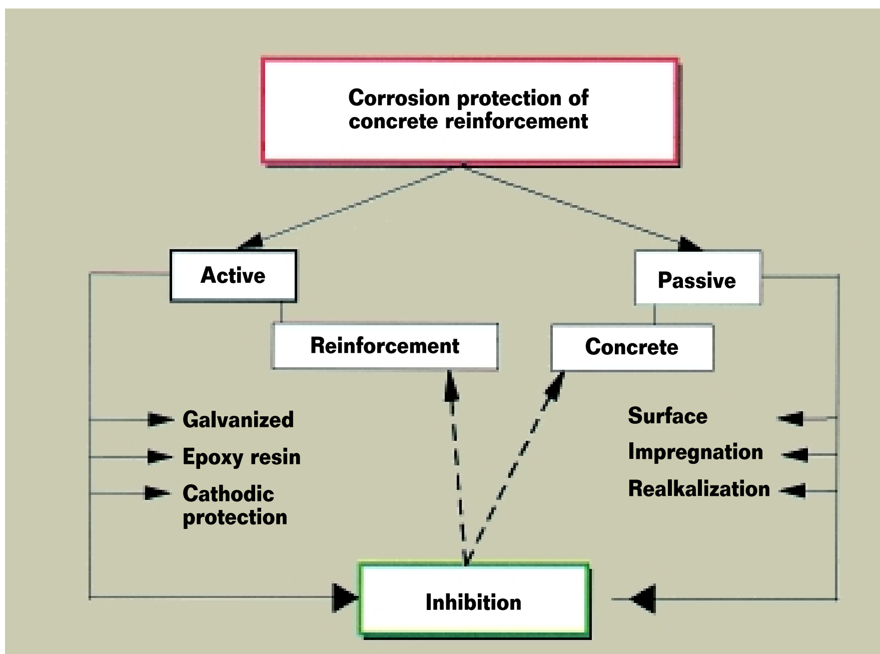
†Trade name.

FIGURE 1



Types of corrosion inhibitors for concrete.

FIGURE 2



Methods of protecting the concrete reinforcement from corrosion.

The data indicate that the effectiveness of MCIs increases substantially with elevated dosage rates. As dosage rates were increased to 3 L/m^3, the level of corrosion activity became statistically insignificant. This suggests that proper dosage is an important issue when using MCIs in a fresh concrete mixture.

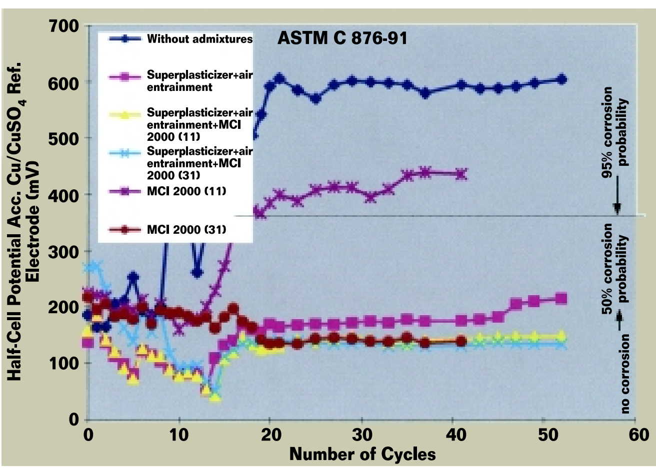
TABLE 1
CONCRETE COMPOUNDS FOR RESEARCH

		Compound Label					
Components:	Units	I	II	III	IV	V	VI
Cement PC 30z 45 s	kg/m^3			356			
w/c	—	0.5	0.38	0.35	0.39	0.5	0.5
Admixtures:							
Superplasticizer	% on weight of cement	—	2.0	2.0	2.0	—	—
Air entraining agent	% on weight of cement	—	0.05	0.05	0.05	—	—
MCI	L/m^3	—	—	1.0	3.0	1.0	3.0

MCI Surface Impregnation Treatment Study

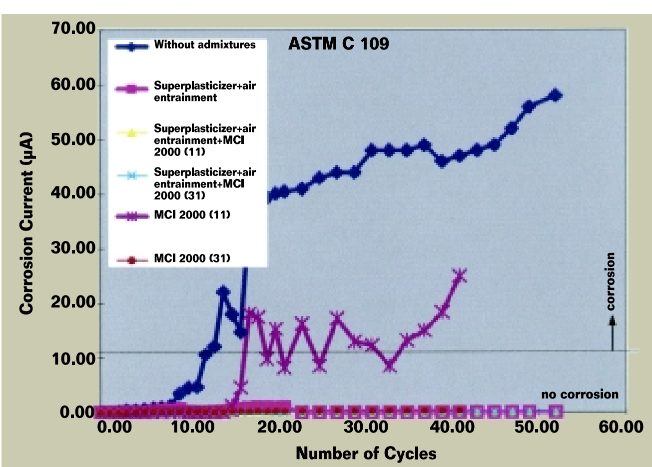
Long-term testing of concrete with MCI surface impregnation was begun in November 1994. After 4 years of continuous testing, it was concluded that the effectiveness of MCIs was observed and confirmed by the test data. Significant differences were found between MCI-treated and non-treated specimens.[14]

FIGURE 3



Corrosion potential vs time.

FIGURE 4



Corrosion potential vs time.

Steel rebar was embedded in the specimen blocks. The rebar was 13-mm diameter polished steel. It was covered by 3 cm of concrete. The concrete used in the preparation of the specimen blocks was mixed with NaCl (3 kg/m^3) to quickly activate the corrosion process. A 3.5% NaCl/water solution was then placed in direct contact with the surface of the specimen. The solution was applied for 1 week (40°C, 100% RH), then dried for 1 week (50°C, 30% RH). This procedure was designed to simulate an accelerated real corrosion process in the field.

After 1,311 days of continuous testing, the control specimens were totally corroded. The average corrosion rate was 73 to 92 µm/y. The specimens that had been treated with MCIs experienced corrosion of only ~10 to 12 µm/y, and in some cases there was little or no corrosion. The corrosion process with MCI-treated specimens was 17% that of the untreated control group specimens.

Several cracks were observed on the control specimens. The study data indicate that cracks with a width ≥2 mm tended to retain more air and water in their cavities. This condition seemed to aid in a greater buildup of electrolytic response (which was caused by polarization) between the bars. Figure 5 shows the occurrence of cracks on the control specimens and the absence of similar cracks on the MCI-treated specimens (after 1,311 days of continuous exposure).

It may be premature to estimate how these test periods correspond to real environments in the field. However, it can be concluded that when MCIs were applied, the corrosion speed was significantly reduced by more than 83%. Therefore, if the test specimens were to be placed in the natural environment, the corrosion rate of the rebar would be ~10 to 12 µm/y. The coefficient number of this rate could be calculated as 5.2 to 6.6 times the test period. In other words, the experimental period to date—4 years—should correspond to 20 to 24 years in the natural environment for MCI-protected products.

Conclusion

The goal of this research was to identify the influence of migratory inhibitors on steel rebar corrosion in concrete. MCIs were added to a fresh concrete mixture or used for surface impregnation of existing concrete structures. The study of MCIs was based on procedures defined and modified from the ASTM G 109 standard. The results clearly indicate that the examined migratory inhibitors are compatible with the components of the concrete structure. Results of sample analysis indicate that, with proper dosage, MCIs significantly retard corrosion. MCIs play an important role in the delay of reinforcement steel corrosion in concrete.

FIGURE 5

(a) (b)

The appearance of untreated and MCI-treated specimens.

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Volatile Corrosion Inhibitor Coatings

MICHAEL PRENOSIL

Volatile corrosion inhibitors (VCIs) are organic materials that protect metals against corrosion by emitting vapors. This study shows that VCIs, combined with sulfonates (contact corrosion inhibitors), can retard corrosion in several different coating systems.

Coatings applied directly to metals normally use conventional corrosion inhibitor pigments such as zinc, aluminum, zinc oxide (ZnO), modified ZnO, and calcium ion-exchanged amorphous silica gel.

Using corrosion inhibitor pigments has several disadvantages. Some pigments contain metals that are toxic. Several, including metallic zinc, have high densities and settle. A number of pigments react with the resins in the coating. Additional pigmentation also requires added wetting agents that may affect corrosion resistance.

Volatile corrosion inhibitors (VCIs) are unique. They are organic compounds that protect metal surfaces by emitting a vapor such as an amine-based compound. The nitrogen on the amine has two electrons that are attracted to the polar metal surface. Once it is attracted to the metal, the rest of the molecule is very hydrophobic and repels water to significantly retard corrosion.

B.A. Miksic, et al.,[1-3] and Y.I. Kuznetsov, N.N. Andreev, and their colleagues[4-7] studied several amines, their derivatives, and imines used as VCIs. VCIs migrate from the coated area to the unprotected metal area. Metals coated with these VCI paints corrode very little in scribed areas since the films are self healing—the VCI evaporates and redeposits itself where the coating has been scratched. Many VCI coatings also contain other corrosion inhibitors to enforce the corrosion-resistance process.

I.L. Rosenfeld, et al.,[8] and N.N. Andreev[9] measured corrosion inhibition by using saturated vapor pressure. N.N. Andreev also used x-ray photoelectron spectroscopy to show the formation of a protective layer by vapor-phase transfer.[4] B.A. Miksic, et al., developed surface analysis methods using electron spectroscopy for chemical analysis (ESCA), x-ray photoelectron spectroscopy (XPS), secondary-ion mass spectroscopy (SIMS), and ion scattering (ISS).[10]

VCIs have been used for years to temporarily protect metals from corrosion in extreme conditions found on automobile underbodies, offshore drilling decks, storage tanks, naval vessels,[11-12] and in the petrochemical industry.[13]

VCIs formulated with standard resins in coatings have largely been ignored for use in industrial maintenance coatings. The reasons VCIs have not been used in coatings include:

- Many are temporary films because they can be removed easily.
- Some VCI coatings are soft, tacky, or even oily.
- VCIs have been used at fairly low levels in conventional industrial coatings. Higher levels may be needed to show the self-healing effect.
- Corrosion protection may not be the only requirement in a coating. Color limitation can be a concern, film hardness may be important, or a high gloss may be needed.

There are many ways to circumvent these limitations. Even though these coatings can easily be removed, they can be permanent where high abrasion resistance is not a concern. Modifying typical industrial solvent-based coatings with VCIs is possible.

Waterborne coatings can also be modified with VCIs. VCIs are solvent- and water-soluble compounds that can be incorporated into waterborne coatings by emulsification, adding cosolvents, or simply dissolving them in water. Tack can be eliminated by adding pigments, waxes, hard resins, or curing agents in some cases. Care must be used to maintain good adhesion and compatibility in these situations.

TABLE 1

WATERBORNE ALKYD FORMULATIONS

Material	Manufacurer	Control	15% VCI	32% VCI
EPS-2601 (78%)	EPS	54	48	38.9
12% Mn	Condea	1	1	0.8
Active-8	R.T Vanderbuilt	1	1	0.8
Sag 5440 defoamer	Union Carbide	0.8	0.8	0.7
Water		43.2	38.6	35.1
VCI-M (61%)	Cortec	10.6	23.7	
Totals		100	100	100

TABLE 2

ASTM B 117. 500-H SALT SPRAY RESISTANCE

Type	Film Thickness (mils/μm)	Corrosion Rating(A)	Scribe Rust(B)
VCI latex	2.2/56	10	10
VCI epoxy	1.7 to 1.9/43 to 48	9	9
VCI petroleum	1.5 to 1.9/38 to 48	8	9
Water-based alkyd	1.7 to 1.8/43 to 46	5	3
15% VCI-modified water-based alkyd	1.9/48	8	10
32% VCI-modified water-based alkyd	1.6 to 2.1/41 to 53	8	10
Solvent-based epoxy	2.0 to 2.2/51 to 56	7	5
Zinc-rich solvent-based epoxy	1.9 to 2.4/48 to 61	0	(C)

(A)ASTM D 1654- 92 Procedure B rating of unscribed areas
10 = no corrosion, 5 = 11 to 20% corrosion, 0 = 75% and over.
(B)ASTM D 1654- 92 Procedure A rating of failure at scribe.
10 = no creepage, 5 = 0.125 to 0.1875 in. (0.32 to 0.48 cm), 0 = 5/8 or more mean average.
(C)Entire surface corroded. Creepage could not be evaluated.

Experimental Procedure

This study examines four temporary VCI coatings, one permanent epoxy VCI coating, two typical epoxies with no VCIs, and a waterborne alkyd with no VCIs. The VCI waterborne alkyd formulations are direct comparisons to a standard waterborne alkyd with the same resin, driers, and cosolvent.

MATERIALS

- **VCI petroleum-based coating:** A proprietary blend of oxidized petrolatum, calcium salts blended with a low level of petroleum sulfonate, amine carboxylates, and mineral spirits.
- **VCI latex coating:** Acrylic latex, calcium salt of organo sulfonic acid, and amine carboxylates.
- **VCI solvent-based epoxy:** Bisphenol A epoxy with aliphatic amine, a blend of oxidized petrolatum, calcium salts blended with a low level of petroleum sulfonates, amine carboxylates, and mineral spirits.
- **15/32% VCI-modified water-based alkyds:** Engineered Polymer Solutions (EPS). An EPS 2601 alkyd, calcium salt of an organo sulfonic acid, and an amino carboxylate. Table 1 shows the formulation.
- **Water-based alkyd:** EPS 2601 (Table 1).
- **Typical epoxy coating:** Bisphenol A, an aliphatic amine with a standard corrosion pigmentation, and other pigments. LX07521 high-solids epoxy primer (Davis-Frost, Inc.).
- **Zinc-rich epoxy primer:** Bisphenol A, aliphatic amine with a high level of zinc pigment, 3921 epoxy (Belzona®).

SAMPLE PREPARATION

All epoxy coatings were given a 1-h induction period after mixing. The coatings were drawn down using a drawdown bar on cold-rolled steel to a dry-film thickness (DFT) of 1.5 to 2.5 mils (38 to 63 μm). They were air-dried for 7 days at room temperature before testing them in a salt spray cabinet (ASTM B-117) (Tables 2 and 3). All coatings were scribed with a vertical line.

Results

All of the VCI-modified coatings are softer than standard non-VCI-modified coatings. VCI coatings, however, offer better corrosion resistance (Table 2). The VCI solvent-based epoxy and the VCI petroleum-based coating were still in good condition with <5% corrosion after 1,000 h (Table 3 and Figure 1).

VCI TEMPORARY COATINGS

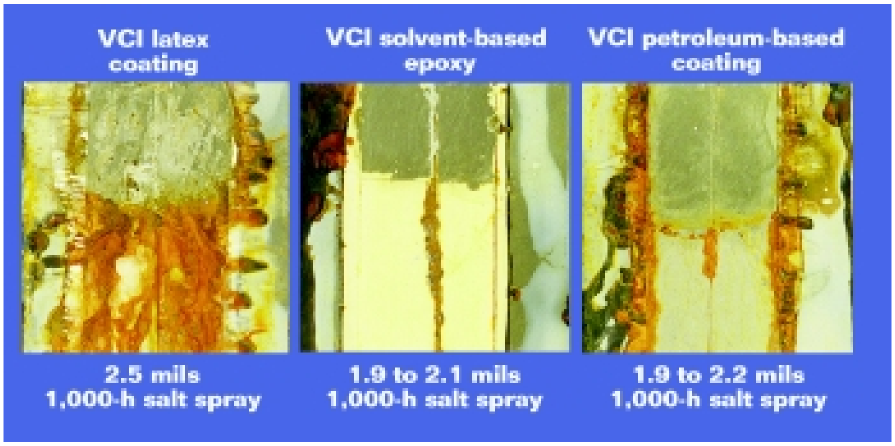
Two temporary coatings were tested: a VCI latex and a VCI petroleum-based coating. After 500 h of salt spray testing, both showed very strong VCI effect and no corrosion at the scribe (Table 2 and Figure 2). After 1,000 h of salt spray, the temporary VCI coatings began to fail (Table 3 and Figure 1). This effect is most noticeable with the VCI latex, which shows the greatest change. It went from no corrosion at 500 h to ~50% corrosion at 1,000 h in the salt spray cabinet.

The petroleum-based temporary coating containing VCI showed only a minor degree of corrosion at 1,000 h (Table 3 and Figure 1). This coating's more hydrophobic nature is the reason for the significantly better results.

VCI PERMANENT COATING

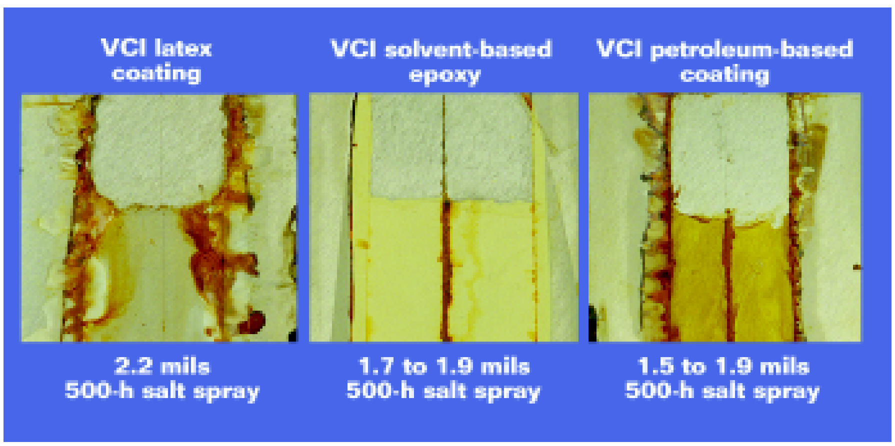
The VCI solvent-based epoxy showed the best corrosion resistance of all coatings tested. It is considered a

FIGURE 1



The VCI solvent-based epoxy and VCI petroleum-based coating had <5% corrosion after 1,000 h in a salt spray test.

FIGURE 2



After 500 h of salt spray testing, a VCI latex and VCI petroleum-based coating showed no corrosion at the scribe.

TABLE 3

ASTM B 117. 1,000-H SALT SPRAY RESISTANCE

Type	Film Thickness (mils/µm)	Corrosion Rating[(A)]	Scribe Rust[(B)]
VCI latex	2.5/64	1	6
VCI epoxy	1.9 to 2.1/48 to 53	8	7
VCI petroleum	1.9 to 2.2/48 to 56	8	7
Water-based alkyd	1.6 to 1.7/41 to 43	1	4
15% VCI-modified water-based alkyd	1.4 to 1.6/36 to 41	0	7
32% VCI-modified water-based alkyd	2.1 to 2.4/53 to 61	4	6
Zinc-rich solvent-based epoxy	2.0 to 2.3/51 to 58	0	[(C)]
Solvent-based epoxy	2.0 to 2.4/51 to 61	7	[(D)]

[(A)]ASTM D 1654- 92 Procedure B rating of unscribed areas.
10 = no corrosion, 5 = 11 to 20% corrosion, 0 = 75% and over.
[(B)]ASTM D 1654- 92 Procedure A rating of failure at scribe.
10 = no creepage, 5 = 0.125 to 0.1875 in. (0.32 to 0.48 cm), 0 = 5/8 or more mean average.
[(C)]Coating delaminates when dried.
[(D)]Entire surface corroded. Creepage could not be evaluated.

permanent coating, although it is somewhat soft at <6B pencil hardness. The scribe corrosion resistance was also very good (Tables 2 and 3 and Figures 1 and 2).

VCI WATER-BASED ALKYDS

Two waterborne VCI-modified alkyd coatings were run as a direct comparison to a waterborne alkyd without any VCIs (control). These formulations were not optimized—they were prepared simply to show the advantages of using VCIs in waterborne alkyds.

At 500 h of salt spray exposure, the 15 and 32% VCI-modified water-based alkyds showed no scribe rust compared to considerable rust on the control (Table 2 and Figure 3). The control did not have pronounced scribe rust; however, there was considerable general rust near the scribe. At 1,000 h, there was significantly more corrosion with all waterborne alkyds. Highly optimized formulations may have provided good protection. This alkyd also may not be able to last 1,000 h at <2 mils (51 µm) thickness.

NON-VCI EPOXY COATINGS

Epoxy coatings are generally very good primers. In this study, two off-the-shelf epoxies were tested in the salt spray cabinet. One zinc-rich primer failed severely after 500 h in the salt spray cabinet (Table 2 and Figure 4). Another solvent-based epoxy delaminated after 1,000 h of salt spray exposure and began to rust at the scribe (Table 3 and Figure 5). The manufacturers recommend that topcoats should be used with these primers to maximize coating performance. However, having a primer with excellent corrosion resistance alone is an advantage. See the VCI epoxy shown in Tables 2 and 3.

Conclusions

The VCI coatings evaluated here are highly modified standard latex, epoxy, alkyd, and petroleum-based coatings that have excellent corrosion resistance. They can be used for many practical applications based on end use, environment, cost, and stability.[14] VCI coatings are an alternative to coatings containing corrosion-inhibiting pigments, although they can be used with such pigments.

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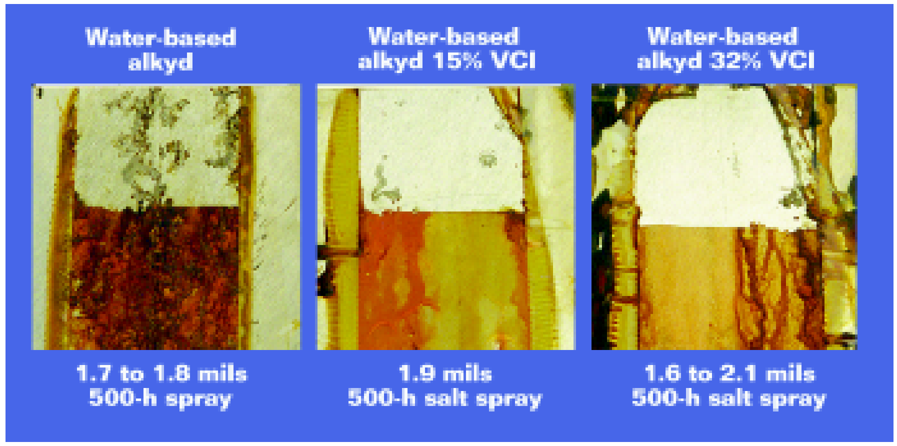
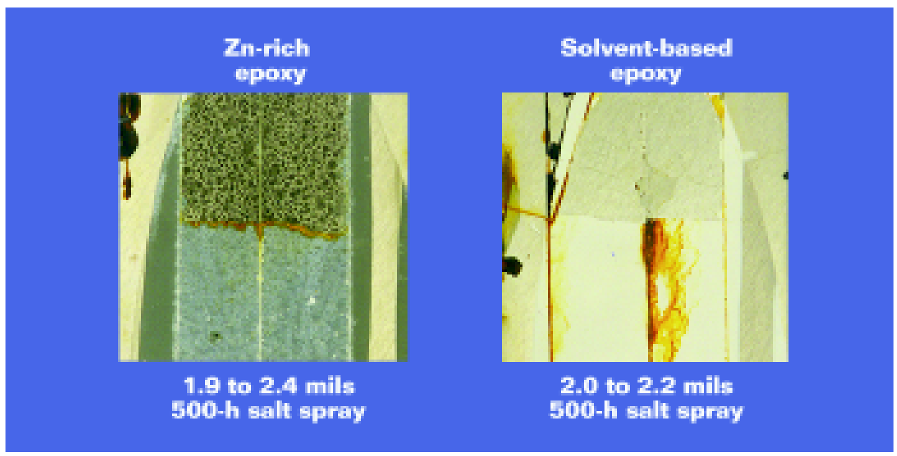
FIGURE 3



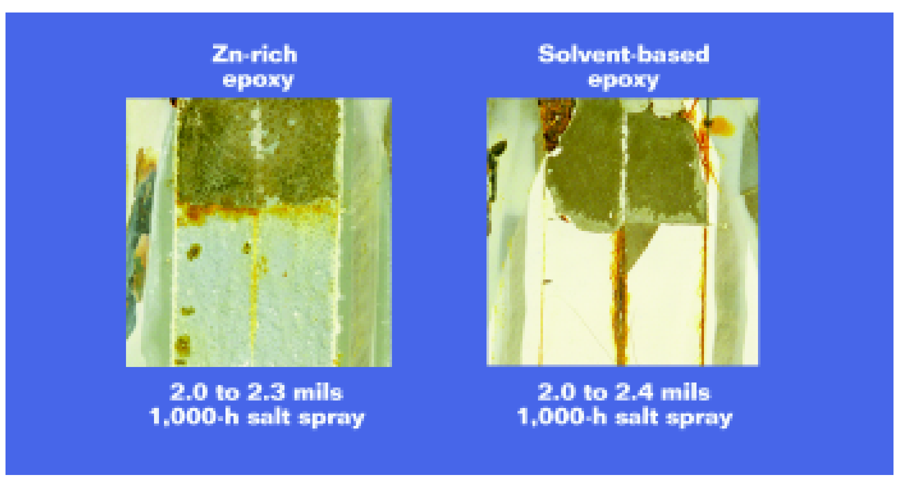
At 500 h of salt spray exposure, the 15 and 32% VCI-modified water-based alkyds performed better than the control.

FIGURE 4



This zinc-rich primer failed after 500 h in the salt spray cabinet.

FIGURE 5



A solvent-based epoxy delaminated after 1,000 h of salt spray exposure.

Vapor Corrosion Inhibitor Field Applications in Electronics

Boris Miksic, FNACE, and Anna M. Vignetti

This article identifies and documents examples of the successful use of vapor-phase corrosion inhibitors (VpCIs) in the field to protect electronics and electrical systems. Ongoing studies and analysis conducted worldwide have deemed VpCIs an effective form of protection. The myriad field and industrial applications of VpCIs prove advantageous for the military, electronics companies, utilities, and many others.

In the last decade, the electronics and electrical industries have increasingly used vapor-phase corrosion inhibitors (VpCIs) for circuit protection. As electronics continue to shrink in size and grow in capacity, the importance of corrosion control increases because even microscopic levels of corrosion can be devastating. Despite today's unprecedented level of knowledge regarding the causes of corrosion in electrical circuits, many electronics manufacturers and assemblers have yet to embrace new technologies. Some apply their favorite conformal coatings and leave the end user or system integrator to deal with the consequences. The results of this singular approach are often catastrophic to electronic equipment. Without additional corrosion-inhibitive procedures, electronics, which are exposed to ambient atmospheric conditions, can fail prematurely. Consequently, it is crucial that both industry and the end user understand that successful strategies and tactics can provide a superior protection solution. Applying VpCIs can quickly, efficiently, and economically minimize corrosion's impact on electrical and electronic systems.

The Mechanism of VpCI Activity

VpCIs can be classified in the following three groups and are ranked according to their electrochemical mechanisms: anodic, cathodic, and mixed (both anodic and cathodic).

ANODIC

Anodic inhibitors prevent metal corrosion by anodic passivation. They play a vital role in the anodic process. An anodic inhibitor increases the corrosion potential and decreases the corrosion current density.

CATHODIC

Cathodic inhibitors can exhibit two very different effects. They can either slow the cathodic reaction itself or selectively precipitate onto the cathodic sites, actually increasing circuit resistance. This circuit resistance restricts the diffusion of reducible species to the cathodes.

MIXED

Mixed inhibitors are compounds in which the electron density distribution causes the molecules to be attracted to both anodic and cathodic sites. They are adsorbed onto the metal surface, creating a monomolecular layer that influences the electrochemical activity at both the cathode and the anode. These inhibitors are more desirable because of their universal effect on the corrosion process.

VpCIs are mixed-inhibitor systems based on aminecarboxylate chemistry. They inhibit the cathodic process by incorporating one or more oxidizing anions in an organic (amine) molecule of VpCI. The nitrogen of the amine group can enter into a coordinate bond with metals, thus enhancing the adsorption process. The adsorption of cations increases the overpotential of metal ionization and slows the corrosion process. The inhibitor's monomolecular film serves as a buffer that maintains the pH level at its optimum range for corrosion resistance.

The inhibitor's adsorption process is not instantaneous. It requires a defined time period to form the adsorbed inhibitor layer on the target metal surface. Two issues must be identified to ensure successful adsorption:

- The surface area, which the molecules occupy, and the necessary molecular binding energy.
- VpCI molecules are water-soluble and possess more binding energy to metal surfaces than that of water dipoles. Also, they create strong exothermic reactions that can displace surface water—this establishes an anchor point that prevents the corrosive species from reaching the metallic surface (Table 1).

TABLE 1

BINDING ENERGIES OF VpCI TO THE METAL SURFACE

Molecule	Binding Energy to Surface (Kcal/mol [kJ/mol])
Water	~43 (180)
VpCI - A	~150 (628)
VpCI - B	~800 (3,347)

VpCI Test Example

CIRCUIT BOARDS PACKAGED IN VpCI-COATED CORRUGATED BOX

A cellular phone manufacturer experienced corrosion problems when its products were shipped around the world. The products ranged from individual cell phones to large networks. Because it is used in many countries, the equipment is often subjected to extreme temperatures and other corrosive atmospheres.

Existing packaging allows moisture to penetrate, creating a strong possibility of corrosion. The manufacturer wanted to protect the electronics that were being shipped in corrugated cardboard boxes without adding shipping labor or part numbers. As a result, the following tests were performed:

BACKGROUND

The manufacturer was already using two corrugated boxes with an electrostatic dissipative (ESD) protective coating designed for circuit boards.

PROPOSED REMEDY

Apply a VpCI coating over the ESD coating and test circuit boards to provide multimetal corrosion protection.

METHODS

- F-12 cyclic corrosion test (modified).
- Razor blade test (Table 2).
- Surface resistivity test.

MATERIALS

- F-12 test kit.
- Razor blade test.
- VpCI liquid coating.

PROCEDURE

Two circuit boards were tested for surface resistivity before applying the VpCI coating solution. Box #1 surface resistivity was 10^6 to 10^7 Ω^2. Box #2 surface resistivity was 10^6 to 10^7 Ω^2.

VpCI liquid coating with a viscosity of 20 to 21 (Zahn cup #2) was prepared. To adjust the viscosity, S-50 thickener was used. One of the boxes was coated with VpCI liquid coating at a coating weight of 15 g/m^2. The other box was not treated.

After applying the VpCI solution, the boxes were placed in an oven set at 40°C for 2 h to dry. After drying, surface resistivity was checked again. VpCI box surface resistivity was 10^6 to 10^7 Ω^2. Non-VpCI box surface resistivity was 10^6 to 10^7 Ω^2.

The razor blade and F-12 tests were performed according to the standard procedures for each, using eight cycles for the F-12 test.

RESULTS

Significant staining (oxidation) of the solder mask was observed on the unprotected circuit board (Figure 1). The VpCI-protected circuit board looked exactly as it did before testing—no oxidation or staining was observed (Figure 2).

Surface resistivity of the two boxes was tested after the F-12 test. The results are as follows:

- VpCI liquid-coated corrugated board provides very good corrosion protection to circuit boards.
- A VpCI coating can be applied over the ESD coating and does not alter the ESD properties.

TABLE 2

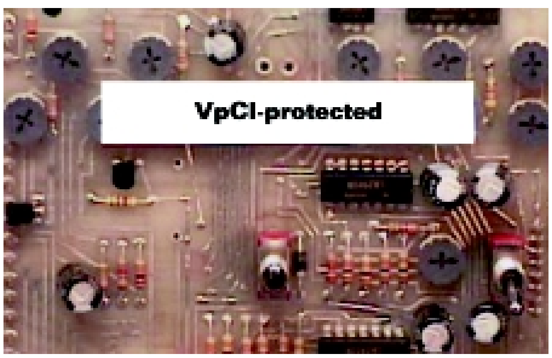
RAZOR BLADE TEST

Material 1	CS Panel #1	CS Panel #2	CS Panel #3	Aluminum Panel #1	Aluminum Panel #2	Aluminum Panel #3	Copper Panel #1	Copper Panel #2	Copper Panel #3
Board #1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Control	Fail	—	—	Fail (slight)	—	—	Fail	—	—

FIGURE 1

The solder mask oxidized on an unprotected circuit board after a field test.

FIGURE 2



A VpCI-protected circuit board looked exactly as it did before undergoing a corrosion field test.

- A VpCI liquid coating applied at a coating weight of 15 g/m^2 (wet) or above is recommended.
- VpCI-coated corrugated board provides corrosion protection for carbon steel, aluminum, and copper.

IN-FIELD APPLICATION

This manufacturer will use corrugated cardboard shipping boxes coated with a VpCI liquid at the minimum coating weight of 15 g/m (wet). Higher rates may provide additional protection in extreme conditions.

Field Applications

VpCI CORROSION PROTECTION SYSTEM FOR STORAGE

Customer

Hong Kong Nuclear Power Group (China)

VpCI Products Used

- Tablets.
- Powder packets.
- Stretch film.
- Emitting devices.
- Foams.
- Paper.
- Electronic spray.
- Water-based coatings.
- Lubricating coatings.

PROBLEM

The customer needed to protect more than $200 million dollars worth of stored spare parts, electronics, and facilities from corrosion. It chose a variety of VpCI products for total corrosion control.

Backup Diesel-Powered Generator

A VpCI coating was sprayed onto the sensitive parts. VpCI emitters and electronic spray were used to protect the control enclosures. VpCI film was used to cover the entire machine.

Small Spare Parts

Bearings were wrapped in VpCI paper while the screws and small parts were treated with a VpCI temporary water-based coating.

Motors and Transformers

Small motors and transformers were wrapped with VpCI stretch film. Large ones were protected with a VpCI temporary coating, then covered with VpCI film. A VpCI lubricating coating was sprayed onto parts requiring lubrication.

VpCI EMITTER

Customer

Electronics manufacturer (Germany)

Product

VpCI emitter

Application

The product was used for fire alarm systems for hotels, airports, factories, shipping centers, museums, and hospitals. Switch boxes and cabinets were equipped with a VpCI emitter before delivery. VpCI vapors protected electronics equipment from corrosion during shipping as well as in later operation, even in unfavorable conditions.

EMITTERS, FILM, ANTISTATIC FILM, FOAM

Customer

Components manufacturer (Illinois)

VpCI Products Used

- Emitting devices.
- Foam.
- Film.
- Antistatic Film.

Indoor protection was needed for up to 2 years

Protected Parts

Cellular phone electronic enclosures, PC boards, ancillary equipment, and installation material needed protection for up to 2 years.

VpCI Application

Packaging electronic enclosures was used to protect the parts from triboelectric charge generation, corrosion, and other related problems (e.g., pitting, oxidation, staining, and galvanic corrosion during shipments).

Account History

The customer was using vapor barrier packing material with desiccants in addition to antistatic bags for protection during shipment. The customer wanted a more cost-effective, less time-consuming export packaging method. VpCI emitters were placed in the electronic enclosures and VpCI antistatic bags were placed over the enclosures. VpCI foam pads and film protected all other miscellaneous electronic equipment.

VpCI PROTECTION SYSTEM

Customer

Chemical manufacturer (Texas)

VpCI Products Used

- Emitting devices.
- Electronic spray.
- Oil additive.
- Powder.
- Coating.

Application

- Mothballing a portion of the plant.
- Electronics: Emitters and electronic spray.
- Interior Cavities: Powder.
- Additive to Oils: Oil additive.
- Exterior: Coating.

Reasons VpCIs Selected

For many years, a wide variety of VpCIs have been used at various locations to preserve new and used equipment. The above products have proven successful and are commonly used for such an application. This portion of the plant could be mothballed for a period of 6 months to 2 years.

Conclusion

Numerous VpCI products can help eliminate the corrosion concerns of electronics manufacturers. VpCIs can improve the life expectancy and high-level performance of electronics. Understandably, no single VpCI application is universally valid. However, VpCI treatment offers positive results when parameters can be defined. Also, combining several VpCI delivery media will, in some cases, probably serve as a better overall method of corrosion inhibition. Therefore, lab bench tests can aid in validating methods and procedures that will support positive field test result applications.

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Water Treatment Applications

Ashish Gandhi

The direct cost of atmospheric corrosion in metals and alloys is an estimated $5 billion annually. The volatile corrosion inhibitor is one weapon for combatting such damage that has recently gained favor in the chemical processing industry.

Volatile corrosion inhibitors (VCIs) condition air or other gaseous environments with trace amounts of inhibitive material to achieve the protective effect. Classic methods of protection involve changing an alloy's composition, changing the environment, or using contact inhibitors. In some instances, these measures may prove impractical because of cost, limited accessibility, risk of contamination, or simply the inability to provide good protection.

VCIs can be used in applications such as air spaces above liquids, condensers, cooling towers and boilers during shutdown or standby, crude oil pipelines, closed-loop cooling systems, open loop cooling systems, brine systems, vessels and other equipment during storage, instrumentation, and control-room equipment.

Water Treatment Applications

In the water treatment industry, the newly developed treatment programs are ambiotic and show inhibition at cathodic and anodic sites. These treatment programs provide three levels of corrosion protection:

1. In the water phase.
2. At the water-air interface.
3. In the air (vapor) phase.

VpCIs are compatible with boiler water and cooling water treatment chemicals. They are used in operational, standby, and laid-up cooling towers as well as closed-loop systems.

VpCIs control corrosion in the multiple phase flow regimes found in oil and gas pipelines and other process equipment.

VpCI building blocks and additives for the water treatment and process industry provides a unique ability to protect in three phases. Incorporating these building blocks and additives into the different formulations used in these industries allows multi-phase, multimetal protection (Figure 1). These building blocks can be incorporated into cooling tower, closed loop cooling systems, and boiler treatment programs.

BOILER SHUTDOWNS (SEASONAL/LONG-TERM LAY-UPS)

The traditional approach for dry layup involves two main processes:

1. Nitrogen gas blanketing.
2. The use of desiccants that must be maintained during the lay-up period and removed prior to boiler start-ups.

The traditional methods for wet layup involve:

- Use of oxygen scavengers.
- Alkaline chemicals for pH >10.
- Use of dispersants and/or antiscalants.
- Use of dicyclohexylammonium nitrite and diisobutylammonium sulfate.

These chemicals are the source of hydroxide ions and use neutralizing inhibitors to neutralize hydrogen ions in the environment. They become volatile only in contact with steam. Examples of neutralizing inhibitors are cyclohexylamine, diethylaminoethanol, morpholine, etc. These compounds are not considered VpCIs since, at use concentrations, they need steam to volatilize. The disadvantage of using silica gel or other desiccants is that once they are saturated with moisture (H_2O), they will release the moisture and create a corrosive environment. Desiccants do not protect against corrosion directly but they do eliminate moisture and provide indirect protection. Oxygen scavengers are not recommended for long-term protection. They neither prevent oxygen ingression nor protect surfaces out of contact with the solution. Moreover, these solutions must be replenished with time, requiring manpower to check levels periodically.

COOLING TOWER SHUTDOWNS (SEASONAL/LONG-TERM LAY-UPS)

The traditional approach to seasonal cooling tower lay-up includes wet lay-up (in places where the temperature does not drop below freezing) and dry lay-up.

Conventional seasonal lay-up programs often use an oil-based product that does not apply evenly. They can foul equipment, posing a tough challenge for disposal. This practice is environmentally unsound. Another problem with oil-based products is they react with rubbers in the system and with roof tars. Oil-based products are a good source of nutrients for various kinds of bacteria, including anaerobic bacteria. This situation promotes microbiological growth in the cooling tower system and bacterial corrosion.

The major shortcoming of conventional lay-up products is that they are strictly contact corrosion inhibitors—they can only protect the parts of the system that they contact. The overhead spaces, crevices, and other hard-to-reach spaces remain unprotected. These areas tend to corrode during downtime because they lack protection. For all of these reasons, a thorough cleaning of the system must be performed before returning the tower to normal usage.

The VpCI Difference

The new method for laying up boilers and cooling towers uses a unique blend of VpCI compounds and contact corrosion compounds in convenient water-soluble polyvinyl alcohol (PVA) bags. The application includes the following steps:

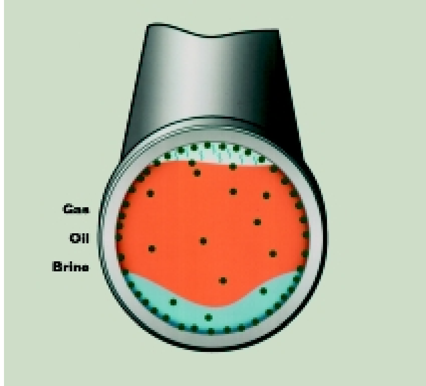
BOILER LAY-UP

Dry Lay-Up

1. After the boiler has cooled down and is safe to enter, the PVA bags are slit open and placed inside the boiler. One bag protects up to 1,000 gal (3,785 L) of void (135 ft^3 [3.8 m^3]) including the surface area of tubes.

2. Close the openings (manholes, etc.).

FIGURE 1



Pipeline section shows active VCI protection at the liquid phase, the vapor phase, and the interface.

Wet Lay-Up

1. Dissolve VpCIs in water (after it is <60°C) and circulate the water for 4 to 5 h.

2. The boiler does not need to be filled completely to protect various void areas because of the migrating nature of the VpCIs.

The VpCIs will reach equilibrium in the void space and protect the metal in the system. These products' performance can be evaluated with corrosion coupons.

COOLING TOWER LAY-UP

Cooling tower lay-up is also conveniently achieved with the help of VpCIs. The towers can be laid up in the following fashion with the help of specially formulated VpCIs in water-soluble PVA bags.

Flushing Lay-Up:

- Place bags into cooling water and circulate the water for 6 to 10 h.
- Drain the treated water and lay-up the tower.

Wet Lay-Up

- Place bags into cooling water and circulate the water for ~6 to 10 h.
- Lay-up the tower with the treated water.

One carton of VpCI water-soluble bags treats up to 1,000 gal of cooling water (or space). VpCIs are compatible with all nonoxidizing biocides. When using oxidizing biocides, it is necessary to be careful and keep the free chlorine levels in check (under 4 ppm) or use a higher concentration of VpCIs.

Advantages

VpCIs have the unique ability to control corrosion in a water treatment system. VpCIs distinguish themselves from conventional contact corrosion inhibitors since they provide:

- Protection in three phases: vapor phase, liquid phase, and liquid-vapor interface (Figure 1).
- Biodegradable and environmentally friendly solutions free of nitrites, phosphates, chromates, and heavy metals.
- Economical solutions for protecting cooling towers, closed-loop systems, and boilers during the interim period, seasonal lay-ups, or long-term lay-ups.
- Economical solutions for niche applications that require vapor phase protection.
- Protection in the presence of moisture and other corrosive environments by forming a corrosion-inhibiting monomolecular layer on the metal itself.
- Cost savings by eliminating the use of expensive cleaning chemicals.
- Increased worker safety and efficiency because of the nontoxic, nonhazardous nature of the products packaged in convenient water-soluble bags.
- Easy startups at the end of the lay-up period with no cleanup required.

Conclusion

VpCI solutions include building blocks (liquid and powder) for formulations, dry and wet layup for cooling towers and boilers, corrosion additives for closed-loop and open loop systems, fire sprinkler systems, antifreeze coolants, and much more.

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A Packaging Concept for the New Millennium

BORIS A. MIKSIC, FNACE, AND ROBERT W. KRAMER

Vapor-phase corrosion inhibitor stretch film packaging is ready to meet the packaging challenges in the new millennium. While polyethylene in the form of stretch film for bundling purposes has been used throughout industry for more than 25 years, the inclusion of environmentally friendly corrosion inhibitors through an innovative technology opened doors in the steel industry.

During the past 3 decades, steel packaging remained basically unchanged using various combinations of kraft paper, corrugated kraft, reinforced kraft papers with polyethylene (PE) laminates and coating, kraft fiberboard, and metal fabricated containers. Commingling materials do not meet demands for recycling or even source reduction to achieve environmental objectives. The new millennium will entail greater focus on environmental concerns and require that all materials produced be recycled.

Inhibited Stretch Wrap Packaging

This concept emerged in the early 1990s when Cortec Laboratories began researching the feasibility of introducing non-sodium nitrite corrosion-inhibiting technology to plastic films. Working with B.H.P. Steel Group and Australian Challenge (Victoria, Australia) researchers found that the technology not only provided corrosion protection but made possible development of new packaging equipment. For nearly 7 years, the company has continued to expand its packaging with vapor phase corrosion inhibitor (VpCI) film, achieving dramatic reduction from prior corrosion claims with standard kraft/poly steel wraps.

At the same time, International Packaging Machines, Inc., of Naples, Florida, built the world's largest stretch wrapper for Sumitomo Light Metals of Nagoya, Japan, to wrap 23-t (20,866-kg) coils of aluminum, 8-ft (23-m) diameter, loaded eye vertical on 2.5-t (2,268-kg) steel platforms without steel banding. Armed with this information, the researchers began developing the high-performance stretch film that Cortec Corp. subsequently patented[1-19] and targeted for tinplate and other metal packaging applications where superior corrosion protection and holding force are critical.

The holding power of stretch wrap through its elasticity curve was far greater than that of steel strapping. The normal cross pattern of two steel bands with break strength of 10,200 lb (4,627 kg) used to secure primary tinplate coils on skids is overshadowed by 120,000-lb (54,432-kg) break strength of 40 wraps 2-mil (50-μm) film stretched 150% (Figure 1). The unique linear molecular structure of plastic stretch film, particularly the use of advanced resin compounds, makes possible superior load-holding force in stretch wrap applications.

Multimetal VpCIs are compounded in the resins used to extrude the film. These VpCIs are chemical compounds that vaporize from the film and condense onto the surface of the metal, forming a thin, monomolecular, uniform, and effective corrosion-protecting layer. It protects even in recessed areas where the film is not in direct contact. The patented Cor-Pak VCI Stretch Film† manufactured with linear low-density PE resins (LLDPE) is transparent, fully recyclable, and nontoxic, with pre-stretch capability up to 350%. This U.S. Food and Drug Administration (FDA)-approved technology makes the film ideal for tinplate and food-processing applications.

System for Tinplate Coils

While the aluminum industry used stretch film for years as an overwrap, Weirton Steel Corp. (Weirton, West Virginia), perfected the viable system for tinplate coils.

The concept to stretch wrap tinplate coils was considered through all levels at the company as a potentially significant cost-reduction alternative. A series of trials was conducted early in 1994 using an IPM Model R0-88† rotary overhead semiautomatic stretch wrapper over a 6-month period with coils averaging 54-in. (137-cm) diameter on 56-in. (142-cm) skid platforms.

Coils of 12-t (10,886-kg) weight wrapped with 2-mil film pre-stretched 250% developed a strong force-to-load strength with 38 to 48 wraps. It became evident in the trials that coil size, as related to skid size, posed a particular problem. The larger the gap between coil and skid corner, the greater the propensity for film puncture and failure at the corner.

Various methods to resolve this problem ultimately resulted in a 2-in. (5-cm) corner radius specification on all skid corners. Trial shipments confirmed projected holding force as well as handling and corrosion protection. Specific trials to evaluate dew point conditions developed some condensation situations, but the VpCI prevented corrosion.

Following extensive trials, the company's management approved purchase of a fully automatic rotary overhead stretch-wrapping machine, which went online January 1995 in placement over an existing coil packaging conveyor line.

FIGURE 1

(a) Steel banded scroll load tinplate.

(b) Roped stretch wrap scrol tinplate.

The linear molecular structure of plastic stretch film allows for strong load-holding force.

It quickly became apparent why pioneering poses greater risks than following prior knowledge. While the American Iron & Steel Institute (AISI)-approved standard skid design is configured for steel strapping, no changes were contemplated for stretch wrapping. Sharp corners became a critical issue as film force-to-load strength was so great that the stretch film began migrating up off the corners and punctured when the gap between coil and skid corner increased because of coil diameter variation. Without positive hold at all corners, holding strength was compromised greatly, causing coils to shift on the skids. Minor modifications were made to resolve these issues. A 2-in. radius on skid corners minimized film puncture, and a 1-in. (2.5-cm) bevel at the top of skid runners flush with lead platform boards allowed film to lock the coil to the skid.

The wrapping sequence originally programmed was further enhanced by the company's Tin Mill engineers to rope or neck down the film width for improved holding force with fewer wraps. Alternating the wrap sequence to cover two corners, then cycling up around the coil opposite the wrapped corners, and repeating them for all four sides, became a major improvement. The program basically consists of five wrap cycles for each side of the skid, five wraps cycling up on the coil, eight wraps at the top and five down, and two final wraps around the skid perimeter to finish. These 40 wraps have proven more than sufficient to hold 12-t coils on the skid in conjunction with a 1/2-in. (1.3-cm) felt pad of 5-lb (2.2-kg) density under the coil to dampen vibration. Average film consumption varies between 1.7 and 2.5 lb (.77 and 1.1 kg) depending on coil and skid size.

Since the company went into full production with stretch wrap film packaging in September 1995, it has shipped in excess of 300,000 coils both domestically and export without failure.

CONTROLLING DAMAGE AND RUST

Figure 2 shows the prepared coil before and after stretch wrapping. The purpose of the package is to protect the coil from damage and rust. Designed to be as airtight and waterproof as possible, each component is there to maintain this condition through all real-world conditions. The VpCI used in the package is not the cure all if the product and package are compromised. It is the important last line of defense that must be understood for proper application. As shown in Figure 3, the steel company has achieved significant reduction in rust claims since the introduction of its stretch wrap pack. The improvements in damage control were adversely impacted in 1998 because of extraordinary conditions at one customer. Currently, the company is focusing on training warehouse and shipping personnel to achieve optimum results. It has worked closely with customers to institute new procedures. In severe situations, it has

† Trade name.

FIGURE 2

(a) (b)

A 12-t coil is shown before and after stretch wrapping.

used third-party consultants to investigate and resolve problems. Figure 4 illustrates progress made by the package design and joint effort with shippers, warehouse, and customers.

Considerable effort was given to trucking firms to help them better understand the handling of tin plate. Manuals with specific instructions were developed for use in training. Random inspections were conducted to ensure directions were being followed. The company firmly believes that 100% use of web strapping of loads on trucks and rail would eliminate most damage. In the meantime, rubber-backed steel-edge protectors provide the best defense against chain damage. Figure 5 shows what can be accomplished by working closely with a customer. The impact of the 1997 damage increase resulted in a new turnover installation at the customer with good results and no rust in 1998. This customer fully expects further reduction in damage.

NEW EXPORT STRETCH PACK

Deviating from "canned" metal case export pack specifications posed a real challenge for the steel company. A "plastic case" package was developed for the company by R.I.G. Packaging (Pittsburgh, Pennsylvania), to integrate into the existing stretch system. Acceptance problems and damage caused by poor handling resulted from lack of understanding of tin plate. A summary of a critical items list was developed and distributed to all parties involved, including customers and insurance carriers. So far, the company reports the export pack has performed very well, reducing material and claims costs.

Construction of the export case is formed in two parts. The top cap has a 20-mil (508-µm) black polypropylene (PP) circle glued to a double-wall corrugated disc in between and sandwiched at the outer edge of a black plastic corrugated edge protector. This cap is placed down over a Super A Flute† corrugated fiberboard circumference or "belly wrap" that is also wax-coated to provide an extra moisture barrier. The export case is placed over and in addition to the standard VpCI stretch pack. The load is then stretch-wrapped a second time for shipment.

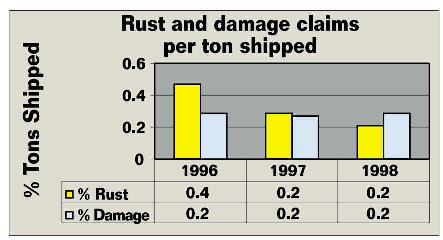
New Markets—New Opportunities

Proven success at steel industry firms spawned new applications at Dofasco, Inc. (Hamilton, Ontario, Canada), Thomas Steel Strip (Warren, Ohio), Interstate Steel (Chicago, Illinois), National Rolling Mills (Philadelphia, Pennsylvania), and Ovako Steel (Sweden), all of which have benefited from elimination of corrosion claims. Wherever there is metals processing, there is opportunity for stretch packaging. For example, TPC Metals (Newark, New Jersey) now packages all loads by stretch-wrapping—even type C loads of uneven size slit mults for export that would otherwise be impossible to securely band on skids. BMAT (formerly U.S. Can) (Chicago, Illinois) transitioned from kraft/poly steel wrap to VpCI poly bags to its current use of VpCI stretch film for all undecorated can stock. It is in the process of converting all litho decorated accordingly.

Trials currently underway at Crown Cork & Seal (Concord, Ontario, Canada) for wrapping cut-length decorated tinplate have been designed to utilize the "roping" technique with VpCI stretch film. This procedure entails programming the wrapping sequence similar to Weirton's work with primary coils, whereby the film is necked down or narrowed to a rope appearance and placed over the top corners for increased vertical holding force.

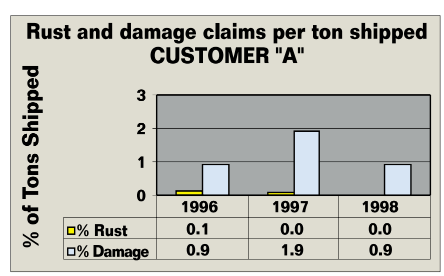
† Trade name.

FIGURE 3



A company achieved significant reduction in rust claims after using stretch wrap packing for corrosion control.

FIGURE 4



Joint efforts with shippers, warehouse, and customers resulted in new procedures to successfully use stretch wrap packaging.

The introduction of molded plastic skid platforms should further enhance the concept of stretch film packaging. New designs accommodate the increased use of stretch wrap/roping.

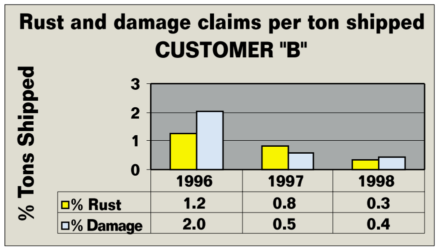
Environmental Advantages

Although improved cost effectiveness would alone justify this new packaging concept for the new millennium, other advantages could become equally or perhaps even more significant in the future. Recyclability of environmentally friendly VpCI films will become more important in the future, particularly as manufacturers become responsible for materials through their useful life cycle and disposal. For the steel industry, it becomes possible to extend a commitment to environmental objectives and recycling to not only the product but also the package. With a simple slice of a razor-cutting knife, <2-lb (.91-kg) film is easily peeled from the load, rolled into a small ball, and tossed into the recycling bin.

Acknowledgment

The authors thank the individuals, companies, and institutions mentioned in this article for their vision and commitment to achieve better corrosion prevention and control.

FIGURE 5



A new turnover installer solved a rust problem for one facility.

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Storage Tank Bottom Protection Using Volatile Corrosion Inhibitors

Ashish Gandhi

Research and fieldwork show that volatile corrosion inhibitors can protect the bottoms of storage tanks used in the oil and petroleum industries. These systems can be used in conjunction with the traditional corrosion control method of cathodic protection.

Storage tank bottoms in the oil and petroleum industries are continuously threatened by corrosive species and moisture present in the environment. When located near the sea, the exposure to saline heightens this problem. Supports and tanks are exposed to exceptionally high loads. For safety and environmental reasons, it is imperative that these base supports and tank bottoms remain safe, secure, and intact, unimpaired by corrosion.

Storage tank bottoms have historically been protected from corrosion using cathodic protection (CP). However, problems arise when there is not complete contact with the base. This occurs as the bottom adjusts to the tank being filled and emptied, causing the bottom to buckle slightly and leave air gaps. Other times, a portion of the base may erode. In either case, electrical continuity is lost. Other means of protection such as protective coatings are not suitable because the coatings are destroyed when the bottom plates are welded together.

Research and field work show that protection can be achieved using volatile corrosion inhibitors (VCIs) under the tank. This works alone or in conjunction with CP.

Corrosion Problem

If general corrosion occurs in the tank bottom, a suitable corrosion allowance can be built in. However, pitting corrosion—where holes are literally drilled through thick steel plate—often occurs instead.

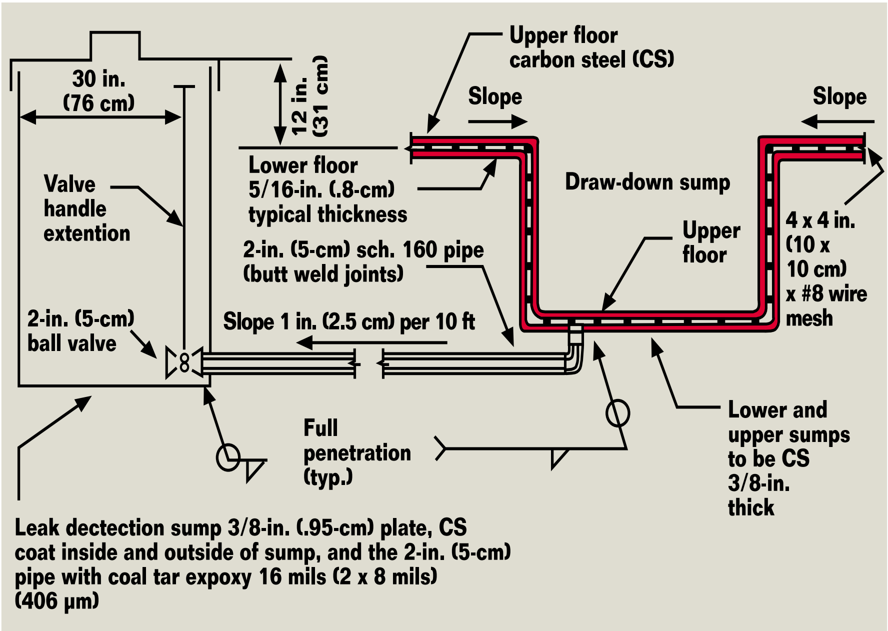
In the past, minor product leakage was acceptable. The cost of the product lost was not always great enough to be a major concern. With today's environmental regulations, however, leakage is a major concern. Vast amounts of groundwater can be contaminated, and cleanup costs can amount to millions of dollars. In extreme cases, the site is not salable on the open market. Also, leaking tanks jeopardize a company's positive public image.

Newer tanks are designed with secondary containment. Double bottoms detect leakage, and concrete or membrane containment limits product migration. Similar problems occur in older systems. VCIs are a suitable solution from both a technical and economic standpoint. These inhibitors have a long history of corrosion protection under wet conditions, corrosive environments, and void spaces.

Corrosion Protection

Even with detection and collection systems, corrosion protection still must

FIGURE 1



Double-steel-floor design with gravity drain—new tanks.

be addressed. Vapor corrosion inhibitors (VpCIs) have been used for many years to solve the basic problem of protecting metal surfaces in a confined space.

VpCIs are a subclass of corrosion inhibitors that have been used by the oil and chemical industries for more than 50 years to minimize difficult corrosion problems. They volatilize at ambient temperature (vapor pressure 0.0001 mm Hg) and redeposit on metallic and other surfaces at equilibrium in confined spaces. The inhibitor stops or retards the corrosion mechanism. It is adsorbed in a monomolecular layer. Some compounds are specific for ferrous metals while others are effective on both ferrous and non-ferrous metals.

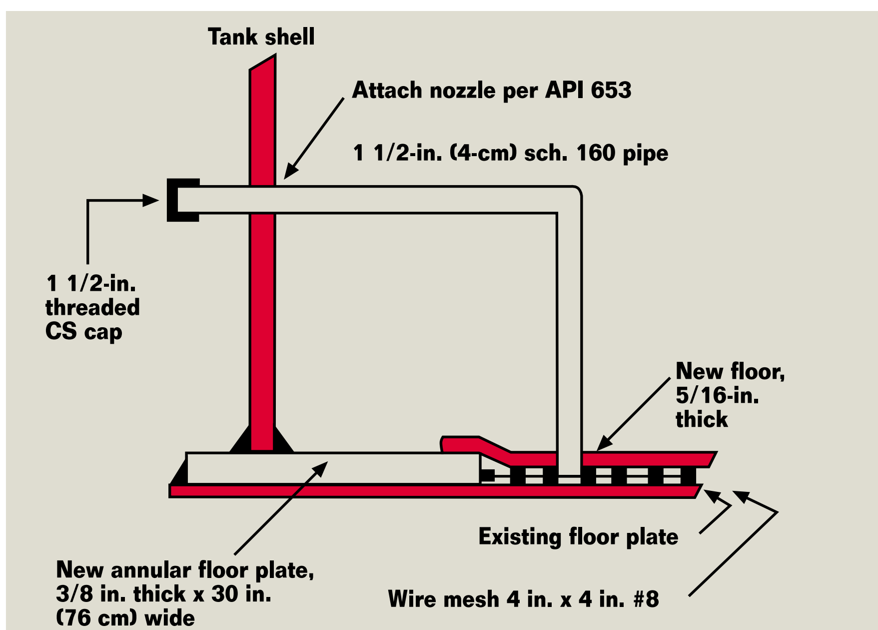
A series of low-toxicity compounds have been developed in the last 20 years,[1] many being in the toxicity range of table salt (2,000 to 3,000-mg/kg oral LD-50). A key characteristic of these materials is that they protect against corrosion in the presence of water vapor, chlorides, hydrogen sulfide (H_2S), sulfur dioxide (SO_2), nitrogen oxides, and other compounds found in a corrosive industrial environment.

These newer VpCIs are being used daily for successful protection. They are produced and used in many forms: pure powder, liquids, "emitters" used in electrical and electronic applications, plastic films and paper used in packaging, and lubricating oil/inhibitor combinations. They are also incorporated into standard solvent- and water-based paint formulations. Companies including DuPont, Conoco Oil, IBM, Motorola, General Motors, Exxon, Mobil, Phillips Petroleum, and others have incorporated these materials into their standard specifications. Organizations such as the U.S. Navy and the U.S. Air Force use this type of protection, reducing expenses significantly compared to conventional preservation methods.[2] The Navy even has an active program evaluating several VpCIs for use in void spaces in ships.

Application to Tank Bottom Protection

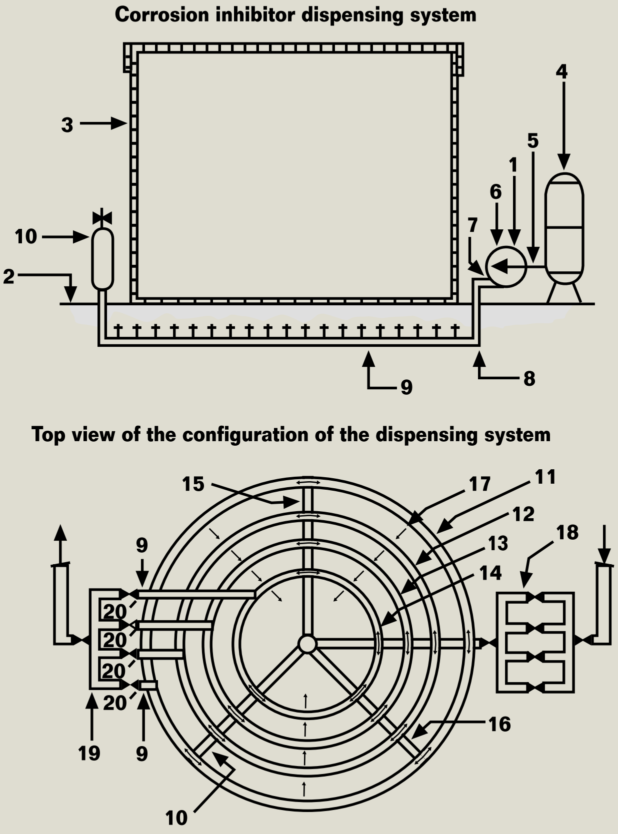
Several years ago, Conoco Oil published a paper on tank bottom protection presenting laboratory testing procedures with positive results.[3] A given quantity of VpCI was mixed with a given volume of sand/gravel mix. Corrosion was monitored over a 2-year period. Real-world experience in void space protection over 15 years has con-

FIGURE 2



Retrofit of existing tank, joint detail for tank shell to floor with double-steel bottom.

FIGURE 3



1. Corrosion inhibitor dispensing system, 2. Concrete support pad, 3. Petroleum type reservoir, 4. Reservoir or chamber enclosure, 5. & 7. Conduit or transfer line, 6. Pump, 8. Dispensing array, 9. Conduit or transfer line, 10. Expansion vessel, 11., 12., 13., & 14. Perforated tubing, 15., 16., & 17. Individual radial extending feed lines, 18. Inlet manifold, 19. Outlet manifold, 20. Relief valves.

Corrosion inhibitor dispensing system in combination with a petroleum reservoir and support pad (patents pending).

firmed the long-term effectiveness of this approach.

This type of protection is incorporated into standards for corrosion control of new and existing tank bottoms. It has also been used in the void space of double tank bottoms.

Tank Bottoms

NEW TANKS

After the subbase of sand/gravel is spread, VpCI powder is applied at the rate of 10 to 20 kg/100 m^2 (2 to 4 lb/100 ft^2). It is mixed into the base with simple hand tools. The tank bottom is then laid out and fabricated as normal. The VpCI slowly distributes itself uniformly throughout the base. At welds, a small amount vaporizes but condenses after the metal cools.

In the case of a concrete base, a VpCI is applied to the surface or a modified form is mixed into the wet concrete. Several organizations have evaluated the migration of this inhibitor extensively and found positive results.[4-7]

EXISTING TANKS

When tanks are being refurbished and new bottom plates are welded in, VpCIs are spread under the plate. When possible, VpCIs are distributed in the adjacent areas. They may also be air lanced from the perimeter under existing tanks, with the powder blown in during the withdrawal process. Ashland Oil evaluated this application process in Pittsburgh, Pennsylvania by analyzing the base for distribution after floor plate removal. Citgo Corp. has adopted another approach that select-injects a 5% solution of VCI-609 in the underbottom sections of fuel oil storage tanks at its Fort Lauderdale, Florida, terminal.

Double Tank Bottom Protection

NEW INSTALLATIONS

After the first bottom is installed, VpCI powder is spread at the rate of 1 to 2 kg/10 m^2 (2 to 4 lb/100 ft^2). Figure 1 shows typical construction. The spacer and second bottom are then welded in place.

EXISTING INSTALLATIONS

VpCI powder is carefully blown into the void to provide uniform distribution (Figures 2 and 3). Alternately, a VpCI solution may be pumped into the void and either left or drained. Either method provides corrosion protection.

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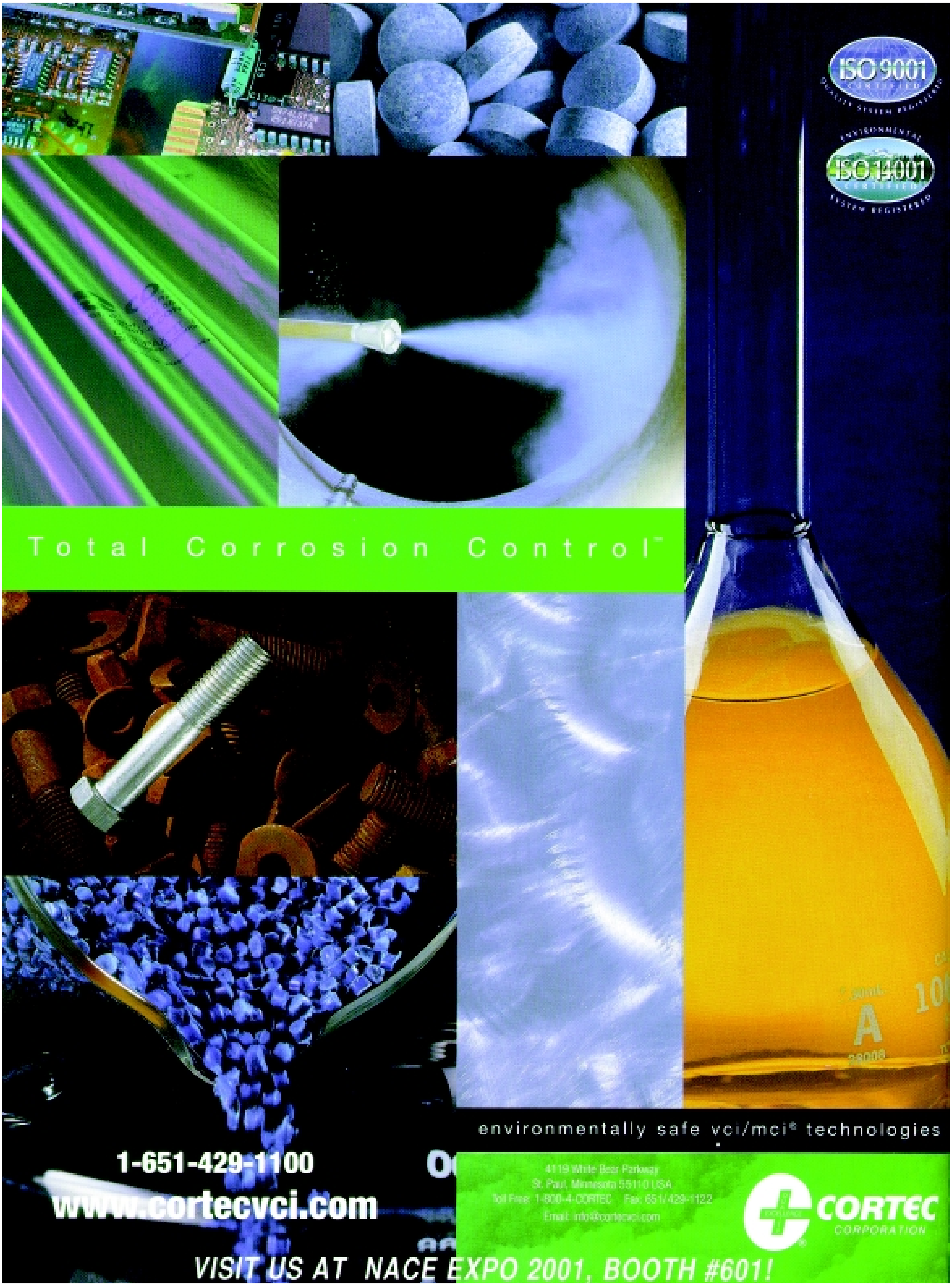
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