# Corrosion Protection of Military Equipment Worldwide

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**Corrosion damages billions of dollars of military assets every year. Military organizations evaluate and utilize a variety of preservation methods that protect equipment from corrosion without compromising war readiness. This article describes types of prevention employed by military organizations and details several laboratory and field applications of vapor phase corrosion inhibitor products and systems used successfully by military organizations worldwide.**

Corrosion significantly affects the performance of military equipment, shortens the time frame for use, and increases the risk of catastrophic failure. The result is billions of dollars in lost assets each year and jeopardized war readiness. Military organizations worldwide continue to take steps to objectively evaluate different corrosion prevention methods in vehicles, aircraft, high-tech electronics, facilities, naval vessels, and weaponry.

Among the different corrosion prevention methods tested, vapor phase corrosion inhibitor (VpCI) technology continues to provide an effective, environmentally friendly, and relatively inexpensive method of controlling corrosion. VpCIs are chemical compounds that have significant vapor pressures that allow molecules to vaporize and then adsorb on metallic surfaces.[1-2] When added in small concentrations, VpCIs effectively check, decrease, or prevent atmospheric corrosion caused by the reaction of the metal with the environment.

## Corrosion Prevention Methods

Table 1 presents four methods currently employed by military organizations to prevent corrosion. They include products that block moisture and other atmospheric contaminants; products used to absorb moisture; alternatives, such as dehumidification; and VpCIs.

## Laboratory and Field Experiments

### LABORATORY TESTING

Specific laboratory testing for ASTM International and Military (MIL) Specification standard test procedures was conducted to support the successful use of VpCIs in field applications.

### FINGERPRINT REMOVAL PROPERTIES TEST

Handling metal components can lead to corrosion as a result of the corrosive nature of the salts in human skin. Because it is difficult to ensure that hands are covered when handling metal equipment, a military test and specification was developed to test the ability to remove fingerprint oils and provide corrosion protection. Table 2 presents the procedure, and the results are shown in Table 3.

### VpCI OIL BASE COATING TEST

A VpCI oil base coating was tested on carbon steel panels (SAE 1010) under highly humid conditions (ASTM D1748[3]), salt spray conditions (ASTM B117[4]), and cyclic environmental conditions (ASTM G85[5]). The test methods simulated the environment under which military equipment may be used or stored. Table 4 shows the results.

### VpCI TEMPORARY SOFT COATING TEST

A VpCI temporary outdoor coating with self-healing properties was tested for various properties according to the military standard method, MIL-C-16173E[6] Grade 1, Class 1. Table 5 presents the results.

### FIELD APPLICATIONS

Many VpCI products and systems used to protect military equipment from

## TABLE 1
## CORROSION PREVENTION METHODS USED BY MILITARY ORGANIZATIONS

| Corrosion Prevention Method | Product Type | Benefits | Disadvantages |
|---|---|---|---|
| Water-displacing products | Petroleum-based (light oils or thixotropic greases) | • Relatively inexpensive<br>• Water displacement<br>• Create a barrier coating on metal surfaces<br>• Excellent permanent protection | • Costs increase with additives (e.g., contact inhibitors, extreme-pressure additives) needed to enhance protection<br>• High labor and material costs for application and removal of product<br>• Use of solvent-based cleaners for product removal makes these products unsafe for the worker and environment |
| Water-absorption products | Silica gel (dessicants) | • Economical alternatives for temporary protection<br>• Effective for storage and shipping<br>• Effective in electronic and electrical operations | • Difficult to calculate specific moisture that will be present (i.e., requires more dessicant and inspection)<br>• Costs increase with the addition of more dessicant and inspections<br>• Airtight seal is required but difficult and expensive to achieve |
| Dehumidification | • Dehumidifier<br>• Vapor barrier bags | • Can be successful if air flow to the metal is totally restricted<br>• Vapor barrier bags are excellent for one-time use (offer a sturdy multilayer film)<br>• Good way to protect electronics | • Dehumidifier<br>➢ Electricity mandatory for dehumidifier and not available in remote locations<br>➢ Difficult to keep a seal on the metal object<br>➢ High cost of equipment and associated upkeep<br>• Vapor barrier bags<br>➢ High costs of materials and labor needed to create air-tight protection<br>➢ Not a good method to use during operations |
| VpCIs | • Anodic inhibitors (e.g., sodium nitrite [$NaNO_2$], dicyclohexylamine nitrite, sodium benzoate)<br>• Cathodic inhibitors<br>• Mixed inhibitors | • Anodic inhibitors<br>➢ Prevent metal corrosion<br>• Cathodic inhibitors<br>➢ Slow cathodic reaction<br>➢ Precipate onto cathodic sites, restricting diffusion of corrosive species<br>• Mixed inhibitors<br>➢ Adsorbed onto metal surface, creating a monomolecular layer<br>➢ Monomolecular film acts as a buffer, maintaining pH at optimum range for corrosion resistance<br>➢ Provide a universal effect on corrosion process | • Anodic inhibitors<br>➢ Negative effect on worker safety<br>➢ Negative effect on environment |

## TABLE 2
## PROCEDURE PER MIL-C-15074,[7] CORROSION PREVENTION, FINGERPRINT REMOVAL

| Step | Procedure |
|---|---|
| 1 | Prepare fingerprint test solution (7 g sodium chloride [NaCl], 1 g urea [$CO(HN_2)_2$], 4 g lactic acid [$C_3H_6O_3$], 1 L deionized water). |
| 2 | Place a pad of gauze on a flat dish and place 1.5 mL of fingerprint solution on pad. |
| 3 | Sand a rubber cork with sandpaper and rinse with deionized water. |
| 4 | Wash five steel panels with methanol ($CH_3OH$) and air dry. |
| 5 | Place fingerprint solution on panels using rubber cork and immediately place in an oven set at 121°C for 5 min. |
| 6 | Place one panel in boiling methanol for 2 min. Immerse a second panel in 1,1,1-trichloroethane ($CH_3CCl_3$) for 1 min. Immerse three panels in a VpCI product for 2 min. |
| 7 | Place all panels in a dessicator with water for 24 h. |
| 8 | After 24 h, open the dessicator and visually evaluate the condition of the panels. |

**TABLE 3**

## MIL-C-15074, CORROSION PREVENTION, FINGERPRINT REMOVAL TEST RESULTS

| Material | Results | Fingerprint Removal |
|---|---|---|
| Methanol | No corrosion | 100% |
| 1,1,1-trichloroethane | Severely corroded | 0% |
| VCI-327 | No corrosion | 100% |

**TABLE 4**

## VpCI OIL BASE COATING TEST RESULTS

| Environmental Test Condition | ASTM Standard Test Method | Coating Film Thickness | Test Duration |
|---|---|---|---|
| Humidity | D1748 | 2 mils (50 µm) | 2,000 h |
| Salt Spray | B117 | 2 mils (50 µm) | 170 h |
| Prohesion | G85 | 2 mils (50 µm) | 500 h |

**TABLE 5**

## MIL-C-16173E, GRADE 1, CLASS 1 RESULTS FOR VpCI TEMPORARY SOFT COATING

| Test | Test Method (Section) | Result |
|---|---|---|
| Material | 3.2 | Pass |
| Toxicity | 4.8 | Pass |
| Film characteristics | 4.6.11.7 | Pass |
| Solvent distillation endpoint | 4.6.1 | Pass |
| Discernibility | 3.6 | Pass |
| Stability | 4.6.6 | Pass |
| Recovery from low temperature | 4.6.6.1 | Pass |
| Uniformity | 4.6.6.1.2 & 4.6.11.4 | Pass |
| Storage stability | 3.73 | Pass |
| Flash point | 4.6.2 | Pass |
| Removability | 4.6.10.1 | Pass |
| Salt spray | 4.6.11.4 | Pass |
| Weather-accelerated | 4.6.11.5 | Pass |
| Flow resistance | 4.6.15 | Pass |
| Sprayability | 4.6.7 | Pass |
| Corrosion | 4.6.8.1 & 4.6.8.2 | Pass |
| Low-temperature adhesion | 4.6.12 | Pass |
| Drying | 4.6.13 | Pass |

corrosion around the world have been tested, approved, and documented. The following field applications vary from simple corrosion protection to more sophisticated solutions.

### VpCI PROTECTION FOR NASA

The U.S. National Aeronautics and Space Administration (NASA) successfully used a simple application of a VpCI coating to protect the O-rings in the space shuttles from corrosion caused by saltwater atmospheric contamination. The coating was approved under MIL-C-16173E (Table 5) to meet NASA's requirement to eliminate or reduce the corrosion.

VpCI products also have proven useful in protecting electronics. NASA performed extensive testing to address VpCI interference with Hyperbolic Ignition and Lox Mechanical Impact Testing. The products were tested and approved for use.[8] Placing the product in enclosed electronic cabinets or boxes allows the inhibitor to form a molecular barrier on the multimetal surfaces of the electrical components. Because the potential adverse effects of molecular layers were of great concern to NASA and the U.S. Navy, extensive testing was conducted that showed VpCI products to be safe for even the most sensitive equipment (i.e., optical coatings and instruments).[9] VpCI products effectively and economically protect telecommunication and radar equipment located in highly corrosive environments.

### VpCI PROTECTION FOR THE U.S. NAVY

The U.S. Navy uses VpCI-emitting devices for electronics on naval aircraft, ships, and air stations.[2,10] These products also are used effectively on other sites on naval vessels to combat corrosion caused by continuous exposure to a salt-laden environment. In addition, VpCI additives are used in coatings and oils.

### VpCI PROTECTION OF WEAPONRY

VpCI products and systems are available in the following forms: film and paper for storage and shipping, lubricating oils, protective coatings, and emitting devices. Each form is a proven, reliable, and effective method for protecting weaponry. Recent testing has been completed on the use of VpCIs in the conservation of infantry weapons in the Armed Forces of the Republic of Croatia.

Degreased and cleaned, unpainted weaponry parts were coated with a thin layer of protective MIL-P-46002B[11] VpCI oil, using a brush or brush soaked in oil (Figure 1). The weaponry was then mounted onto special holders and left for 10 to 15 min. so excessive protective oil could drain into previously prepared containers (Figure 2). The oil-coated weaponry was placed into protective MIL-B-22020C[12] VpCI bags. The bags were sealed with self-adhesive tape or were welded shut using specialized equipment (Figure 3). The protected weaponry was loaded into crates for warehousing, making sure not to damage the VpCI bags. The weapons were stored in different climates—a mild, Mediterranean climate; a cold, mountain climate; and a dry, continental climate.

After 3 years of storage, the protected weaponry was examined for evidence of corrosion. All metal parts and barrels were in excellent condition—including the weaponry stored near the sea in the presence of a significant concentration of chloride salts and weaponry enclosed in plastic bags that were damaged around the mouth of the barrel and sights. The examination verified the protective effect of VpCIs and extended the conservation period, resulting in significant savings for weaponry protection.

## Benefits of VpCI Technology

Through widespread use of VpCI products and systems, military organizations continue to benefit from successful corrosion prevention and the following additional advantages associated with using VpCI technology:

- Ease of application
- Efficiency in application and nonremoval (removal only if necessary)
- Environmentally friendly
- Economic advantages
    - Low-cost products
    - Reduced labor costs for application and removal
    - Reduced maintenance costs
    - Less-frequent reapplication of products
    - Reduced loss of assets
- Enhanced combat readiness
- Extended life expectancy of equipment.

## Conclusions

VpCI technology continues to advance as evidenced by expanded utilization and testing of VpCI products and systems by military organizations for preventing corrosion. VpCI use is effective in protecting the safety of military personnel, eliminating hazardous waste disposal, reducing labor costs, and preserving war readiness. The efficiency and ease of application along with the benefit of nonremoval (in most instances) make VpCI technology a desirable alternative for military organizations.

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**FIGURE 1**

Degreased and cleaned, unpainted weaponry parts coated with VpCI oil.

**FIGURE 2**

VCI oil draining into previously prepared containers.

**FIGURE 3**

Weaponry to be packed in VpCI bags