



VAPOR PHASE CORROSION INHIBITORS (VCIs) FOR PROTECTING SHIPBOARD VOIDS

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ABSTRACT

Void spaces are an inherent part of all ship designs that must balance internal arrangements with hydrodynamic and other ship architecture constraints. These void spaces are for the most part considered to be dry but often they are not as the ship may be using the spaces as ballast. In addition, all void spaces are subject to condensation which contributes to corrosion. The current practice of protecting these voids on CVNs is to use desiccant containers per MIL-D-3263A with desiccant material IAW MIL-D-3716A. A 5 pound dessicant disc is required for each 150 cubic feet of void volume. Desiccant containers add significant weight (over 7 tons) to the Weight of a CVN. In addition, there is a considerable burden on the part of ship's force to dehydrate and restore saturated desiccant containers.

Vapor-phase Corrosion Inhibitors (VCIs) are being considered as an alternative water exclusion technology because VCIs are simple to install and have been used in similar commercial applications for this purpose. To assess the efficacy of using VCIs to protect ship voids, a laboratory testing of commercially available VCIs to determine their effectiveness in protecting blasted steel, pre-corroded steel and coating damaged steel has been undertaken. This paper summarizes the results of laboratory testing, conclusions and recommendations made.

Keywords: vapor phase corrosion inhibitors, volatile corrosion inhibitors, voids protection, corrosion inhibition.

INTRODUCTION

All military assets, whether they are ships, submarines, airplanes or ground vehicles, contain spaces in their structures known as voids. Voids are designed to balance weight and volume constraints. The degree of humidity in these voids varies according to the different environments in which the weapons systems operate. Though some of these voids are coated they are still subject to corrosion. The extent of corrosion in voids varies for a variety of reasons, including exposure to pressurized piping

systems running through them, the use of voids to hold seawater ballast, condensation in vented voids, design deficiencies and the inadequate use of desiccant wheels or bags.

In order to address the potential corrosion issue in shipboard voids, the Office of Secretary of Defense (OSD) tasked Naval Surface Warfare Center Carderock Division (NSWCCD) to perform laboratory testing of selected commercial VCIs under simulated operational environment and to install them into selected dry voids on a CVN 68 class aircraft carrier as a shipboard demonstration plan for determining the effectiveness of VCIs ¹.

VCIs are organic compounds that possess appreciable vapor pressure and consequently can be used to inhibit atmospheric corrosion of metals without being in direct contact with the metal surface. Such inhibitors are placed in the vicinity of the metal to be protected, and they are transferred by sublimation and condensation to the metal surface. These are usually only effective if used in enclosed spaces such as inside packages and in the interior of machinery during shipment²⁻³. VCIs have also been found to be useful for protecting metals in cavities and other hard to reach places⁴.

VCIs should also meet previously established objectives of the Carrier Planning Authority (CPA) for alternative methods for keeping the voids dry and corrosion free:

- To greatly reduce and/or simplify coating repair, thereby avoiding the significant costs associated with current repair procedures or in procuring replacement desiccant containers.
- To replace the desiccant containers currently in use by one of the advanced and efficient VCIs, should it prove to be more universally effective.
- To provide a net lower life cycle cost for the maintenance of shipboard voids. This will result in improved reliability, as well as substantial cost savings due to increased maintenance intervals and improved operational availability and provide self supporting cost benefits to the fleet.

OBJECTIVE

The objective of the laboratory testing was to evaluate the relative effectiveness of VCIs in protecting steel from corrosion under a high humidity environment simulating that found in shipboard voids. These results will serve as complimentary data to field test data that will be taken after installing VCIs into a selected number of voids on a CVN 68 class ship. A secondary objective is to determine the suitability of the test protocol for future VCI material screening for similar applications.

EXPERIMENTAL

VCIs evaluated in the laboratory testing are given in Table 1.

TABLE 1.
VCIs TESTED

Product Code	Product Type
VCI A	Off-white crystalline powder
VCI B1	White crystalline powder
VCI B2	Water solution

Coupon Testing

Three types of samples were tested:

- a) sand blasted and acetone degreased 1010 carbon steel coupons (bare)
- b) 1010 carbon steel coupons exposed to ASTM B117 salt spray for 48 hours to make them rusty (pre-corroded)
- c) 1010 carbon steel coupons coated with standard epoxy coating per MIL-DTL-24441 and scribed diagonally to show the metal underneath the coating (damaged coating).

These three conditions of steel coupons were selected to simulate similar conditions in shipboard voids, i.e., freshly sand blasted bare steel, corroded steel and finally, coating damaged steel. All of the three types of pre-weighed test coupons were placed inside four air tight test vessels:

1. A control test vessel without a VCI and kept at a relative humidity (R.H), level of about 95%,
2. A test vessel where coupons were exposed to VCI A powder and kept at 95% R.H.,
3. A test vessel where coupons were exposed to VCI B1 powder and maintained at 95% R.H.,
4. A test vessel where coupons were exposed to VCI B2 solution spray and maintained at 95% R.H.

The spray application of aqueous solution of VCI B2 was chosen to determine if it would provide a more uniform application than VCI powder application which has the tendency to clog the spray applicator. VCI powders were blown into respective test vessels through a 1" plastic tube using an Abrasive Spot Blaster, Model SB 9005 and laboratory compressed air at a pressure of approximately 10-12 psi. A fiberglass mat was used to cover the top of the test vessel during blowing of the VCI powder to prevent any loss. Once the powder installation was complete, the fiberglass mat was replaced with a tight fitting glass cover and was allowed to stand under laboratory conditions. After 24 hours of conditioning, all of the test vessels were maintained at a R. H. level of about 95% by keeping 500ml of 3% glycerine solution in water in a plastic tray at the bottom of each test vessel. A typical test vessel with all the three types of specimens and VCI A powder installed is shown in Figure 1.

Representative bare coupons in triplicate were removed from each test vessel after 3, 6 and 9 months of exposure and were photographed to document the corrosion condition. In addition, carbon steel specimens were cleaned per ASTM G1 method to remove corrosion products and subsequently dried and weighed. The difference between the initial and final after exposure weights accounted for the weight loss of the metal due to corrosion. From the weight loss data corrosion rates were calculated³.

Pre-corroded specimens exposed in each test vessel were also removed at the same intervals of time and photographed. They lost some loose corrosion products while they were on test and therefore, no attempt was made to reweigh and calculate corrosion rates. Visually, there was no major change in their appearance.

For the coated and scribed specimens exposed, a visual examination was made to see if corrosion occurred in the scribes or not and was documented by digital photography.

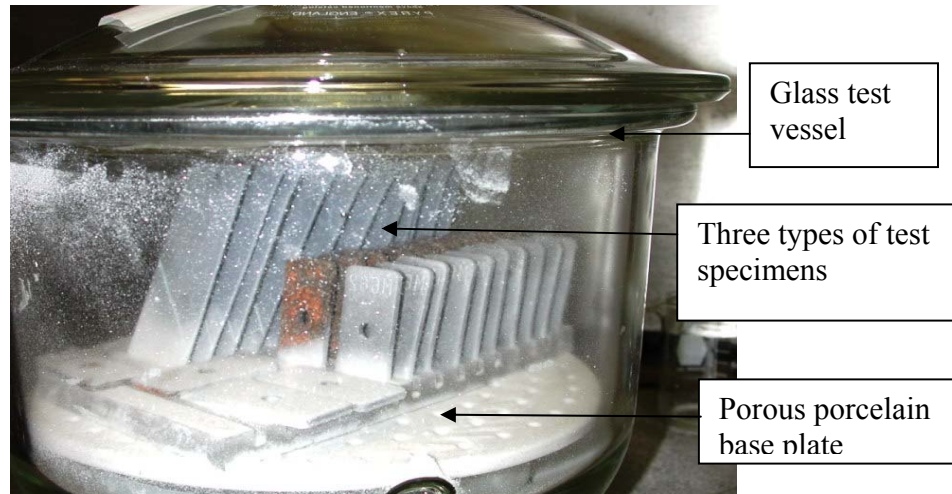


FIGURE 1- A typical test vessel with three types of specimens exposed to VCI A

Electrochemical Testing

The Tafel scan method³ is a well known electrochemical method used to determine instantaneous corrosion rate of metals and alloys in a given environment such as seawater. This method was slightly modified to suit the needs of the present task. Because the dry voids are not likely to be exposed to a harsh environment such as seawater but may be exposed to salt laden moisture, a dilute solution of 0.1M NaCl solution was selected as the test environment. A freshly sand blasted, cleaned and degreased carbon steel coupon was used for the test. Tafel scans were obtained by using sand blasted and cleaned 1010 carbon steel coupon as the working electrode in 250 ml of 0.1M NaCl solution in a Perkin-Elmer corrosion cell. A platinum gauze counter electrode and a solid Ag/AgCl reference electrode were used in the corrosion cell. The sample area of the working electrode exposed was 1 cm² and the scan rate was 0.166 mV/s. A potential of -250 mV to +250 mV was applied versus equilibrium corrosion potential (E_{corr}) and the resulting corrosion current was monitored in each experiment. Tafel scans were obtained in 0.1M NaCl solution mixed with no VCI (control scan), and subsequently in solutions containing 0.5%, 1%, and 2% of VCI A and VCI B1 added separately. Since the results of 0.5% and 1% VCI did not yield sufficient corrosion control, a concentration of 2% VCI was used for rest of the Tafel study.

Shipboard Demonstration and Inspection Plan

The Void Maintenance Strategy Working Group tasked the Carrier planning Activity (CPA) to develop a shipboard demonstration and inspection plan for desiccant container and Vapor Phase Corrosion Inhibitor (VpCI or VCI) effectiveness in CVN-68 Class Dry Voids. The CPA, COMNAVAIRFOR (N43), and NSWCCD selected *USS Harry S. Truman* (CVN-75) for the initial CVN-68 Class shipboard demonstration of an alternative dry void desiccant strategy.

There are approximately 270 dry voids (non-floodable, including cofferdams and sponson voids) on CVN 68 Class ships, distributed throughout the ship. Desiccant containing discs are installed in these spaces to reduce the amount of moisture to control or limit corrosion. According to general specifications for overhauling⁵ it requires a 5 pound disc for each 150 cubic feet of void volume. As there are about 430, 000 cubic feet of void volume in each CVN ship, this requires over 2,800 desiccant discs weighing more than 7 tons.

If a dry void is exposed to high relative humidity and high temperature, small amounts of water will be absorbed. If this void is sealed and not opened, most of this water will be absorbed by the desiccant discs. These desiccant discs are procured under MIL-D-3716, (Desiccant Containers, Dehumidifiers) and are filled with activated desiccant per MIL-D-3716, (Desiccants, Activated for Dynamic Dehumidification). They are regenerated when the silica gel has turned to pink color per paragraph 3.3.2 of the MIL-D-3716. Saturated desiccant containers are reactivated in an oven at 325 degrees Fahrenheit. If the water vapor is not properly absorbed, water will condense on the steel during periods when the steel surface is below the dew point. If the coating is damaged to bare metal, oxidation of the substrate will almost certainly occur. The depletion of oxygen in voids where this process occurs is one of the primary reasons why dry voids, when opened, are hazardous to human life.

Vapor Phase Corrosion Inhibitors (VCIs) are potential alternatives to desiccants. They prevent corrosion by the adsorption of VCI molecules onto areas of bare metal in an enclosure. This adsorption has been demonstrated to be effective in the reduction or elimination of corrosion in commercial ship tanks. The VCI material is generally applied to the tank in a powder form that is sprayed with an applicator. The cost is estimated at about twenty-five cents per cubic foot.

Weight is always an important parameter for Navy ships. CVN 68 Class carriers are in a Stability Status 2; neither an increase in weight nor decrease in stability can be accepted without compensation. In order to modernize the ship, the addition of weight is generally required for new weapons systems and aircraft. Compensation for this modernization weight increase is therefore of significant importance. In this context, the removal of 7 tons of desiccant weight is a viable option to meet this need.

A total of 12 voids were put under Groups D through G and were subjected to different activities as shown below:

TABLE 2.

D. REMOVE DESSICANT CONTAINERS FROM THE FOLLOWING DRY VOIDS:

Work Package Item	Void Access Compartmentation	Service	Void Test Group	Bare Steel test Coupon hung
03-143—6-V	03-138-8-L passage	DRY VOID	III	#43
8-210-9-V	4-210-3-A	DRY VOID	I	#37
8-250-1-V	3-235-1-Q Store Room #4	DRY VOID	IV	

TABLE 3.
**E. REMOVE DESSICANT CONTAINERS FROM THE FOLLOWING DRY VOIDS AND
 INSTALL VAPOR PHASE CORROSION INHIBITOR, VCI A:**

Work Package Item	Void Access Compartmentation	Service	Void Test Group (Volume, cu ft./lbs VCI)	Bare Steel test Coupon(s) hung
01-9-3-V	01-G-3-V	DRY VOID	III (300/9.5)	#20
8-230-4-V	4-225-2-A	DRY VOID	IV (2173/68)	#2 and #3
8-250-3-V	3-235-1-Q Store Room # 4	DRY VOID	IV (1100/34.4)	#5

TABLE 4.
F. REGENERATE DESSICANT CONTAINERS IN THE FOLLOWING DRY VOIDS:

Work Package Item	Void Access Compartmentation	Service	Void Test Group	Bare Steel test Coupon hung
01-C-2-V	01-G-0-A Bosn Store Room	DRY VOID	III	#40
8-215-9-V	4-210-3-A	DRY VOID	I	#28
8-250-5-V	3-235-1-Q Store Room #4	DRY VOID	IV	

TABLE 5.
G. REGENERATE DESSICANT CONTAINERS AND INSTALL VAPOR PHASE CORROSION INHIBITOR, VCI A IN THE FOLLOWING DRY VOIDS

Work Package Item	Void Access Compartmentation	Service	Void Test Group (Volume, cu ft/ lbs VCI.)	Bare Steel test Coupon hung
4-44-1-V	3-44-1-L	DRY VOID	III (800/28)	#22
4-133-1-V	3-133-1-Q	DRY VOID	III (800/28)	#48
8-210-10-V	4-210-2-A	DRY VOID	I (1214/40)	#21

A clean and dry, pre-weighed bare steel coupon was installed in some of these voids and the coupon number installed is given in the last column of Tables 2 through 5, to enable monitoring the effectiveness of VCI A in protecting the voids. These steel coupons will be inspected at least once a year for a period of two years or for duration as practical as possible and the results will be documented in a future report or paper.

VCI A Powder Installation into Shipboard Voids

The VCI installation team proceeded to the ship, *USS Harry S. Truman* (CVN-75) at the Norfolk Naval Ship Yard (NNSY) one day prior to installation and looked at a couple of spaces which accessed the designated voids. The team verified that all of the VCI material ordered had been received and was staged on the hanger deck, just outside the Work Integration Trailer. The VCI installation team was given a short tour of the ship to enable them to become oriented.

On the day of VCI installation, a representative from Naval Air Forces Atlantic (NAF) had gone into the voids and using a laser range finder to determine the actual void dimensions. The volume of each test void was accordingly calculated. Using these updated volume figures, installation personnel made bags with the appropriate amount of measured VCI A for each void. While the VCI installation team went to the first void, designated helpers from NAF delivered the measured bags of VCI A to the hatches of each test void listed under Group E in Table 3 and those under G in Table 5. For each void under Group E and G, its volume in cubic feet and the weight in pounds of VCI A installed are listed in parentheses and are given in the fourth column (see Tables 3 and 5). VCI A powder was applied into each test void using a spreader. When the spreader got clogged and did not work smoothly, the powder was spread by hand as uniformly as possible. Necessary PPE such as a hard hat, safety glasses, gloves and a mask were worn by the persons who installed the VCI A powder. After installing the VCI A powder, a clean and dry pre-weighed bare steel coupon was hung in some test voids as a visual indicator for determining the effectiveness of the VCI A in those voids. As long as the VCI A is effective, the clean bare steel coupon should not show signs of corrosion. Any signs of corrosion on bare steel coupon should indicate that VCI A has depleted in that space and it is time for reapplication.

The following are representative pictures taken onboard the test ship during VCI A powder installation into designated voids.



FIGURE 2 - Control Group Void, 03-143-6-V showing some areas of coating damage



FIGURE 3 - Control Group Void 8-210-9-V



FIGURE 4 - Group F Void, 8-250-5-V showing a coating damaged pipe



FIGURE 5 - Another View of Group F Void, 8-250-5-V with Regenerated Desiccant Containers

RESULTS AND DISCUSSION

Results from Coupon Testing

Three bare steel coupons were removed from each test vessel after each exposure interval and the average weight loss was determined. The corrosion rates were calculated from the average coupon weight loss data³. The corrosion rates obtained are plotted versus exposure time for coupons removed from each test vessel and are given in Figure 6.

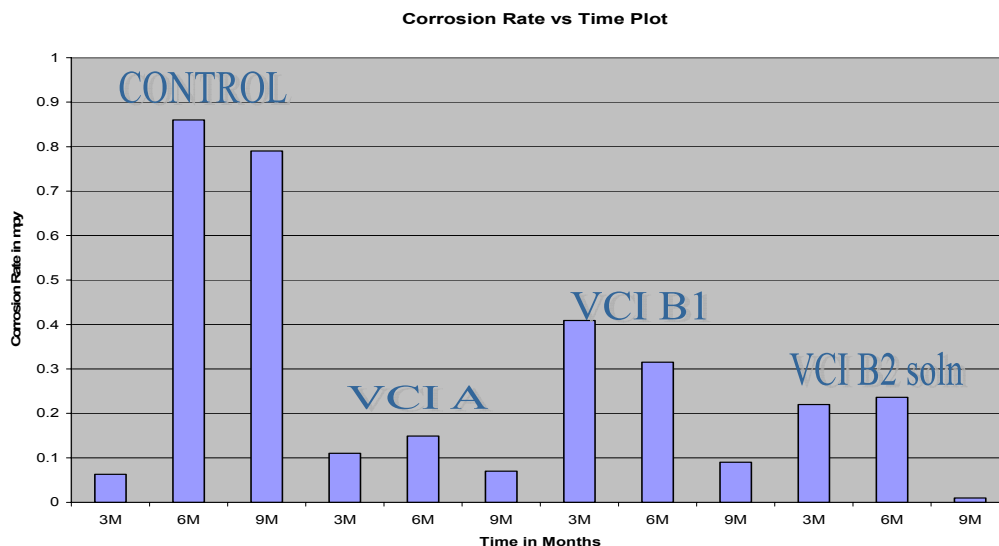


FIGURE 6. Corrosion rates for bare steel coupons removed at different time intervals from four Test Vessels.

As can be seen in Figure 6, the corrosion rate for control specimens after a 9 month exposure is the highest and that for VCI B2 solution sprayed specimens the lowest. The corrosion rates of specimens exposed to VCI B1 powder are lower than the corrosion rates for control specimens of 6 and 9 months exposure but higher than the corresponding values of specimens exposed to VCI A. One specimen removed after 9 month exposure to VCI A showed one or two corrosion spots (see Figure 8, specimen B19) all other VCI A exposed specimens looked clean and without corrosion. The specimens treated with aqueous solution of VCI B2 had a lower corrosion rate than the specimens exposed to VCI B1 powder. But, both the specimens exposed to VCI B1 powder and VCI B2 solution showed spotty corrosion (Figures 9 and 10). Such spotty corrosion may be attributed to insufficient concentration of the inhibitor to protect the entire surface of the specimens. It is known that for optimum inhibition, the concentration of an inhibitor must exceed a certain critical value. Below this optimum concentration, it increases the corrosion at localized areas⁶. Overall, the results show that although all the VCIs tested are effective in controlling corrosion of carbon steel under a high humidity level of about 95% R.H., VCI A showed the best performance. The VCI molecules from the vapor-phase corrosion inhibitors adsorb on bare steel surfaces under high humidity conditions leading to formation of invisible mono-molecular layers which in turn inhibit or protect the steel surface from corrosion²⁻³.

A slightly lower effectiveness of VCI B1 powder versus VCI A powder may be attributed to the lower dosage of the former. For example, 4g of VCI B1 powder was installed versus 25g of VCI A powder for the same volume of the test vessel. These dosages for VCI application were given by the vendors for their respective products. Though not very significant, the solution spray of VCI B2 showed a slightly better corrosion control than the VCI B1 powder. This is worth noting since the application of solution spray can overcome the difficulties of clogging when a powder VCI is installed with a spreader.

Representative carbon steel specimens taken out after nine months exposure from the control, VCI A, VCI B1 and solution of VCI B2 installed test vessels are shown in Figures 7-10. Bare carbon steel coupons from the control test vessel showed some corrosion spots while those exposed to VCI A powder appear mostly clean with only one or two corrosion spots. However, both the test vessel and specimens exposed to VCI A had a lot of condensation making it slippery to remove the samples. The sides of the test vessel and the specimens were wet. Two reasons were postulated for this condition: (1) VCI A powder mix may contain some desiccants that were saturated and (2) the chemicals in the propriety VCI A powder mix are hygroscopic in nature. Bare carbon steel coupons exposed to VCI B1 powder showed a number of corrosion spots compared to those exposed to aqueous solution spray of VCI B2 and to those exposed to VCI A and control specimens. While VCI B1 powder and VCI B2 solution are from the same vendor, the results show that the effectiveness of VCI B2 solution is slightly better than the VCI B1 powder on bare carbon steel coupons. This supports the earlier statement made at the beginning that a solution spray of a VCI may result in a better corrosion control than VCI powder application. This can be attributed to a more uniform distribution of VCI solution spray than the VCI powder distribution onto steel coupons.



a. Front face



b. Rear face

**FIGURE 7 - Control carbon steel specimens after 9 months exposure:
a) front face and b): rear face**



a. Front face



b. Rear face

**FIGURE 8 - Carbon Steel specimens after 9 months exposure to VCI A:
a) front face, b) rear face**



a. Front face



b. Rear face

**FIGURE 9 - Carbon Steel specimens after 9 months exposure to VCI B1 powder:
a) front face, b) rear face**



a. Front face



b. Rear face

**FIGURE 10 - Carbon steel specimens after 9 months exposure to VCI B2 solution:
a) front face, b) rear face.**

Only one of the coated and scribed steel coupons exposed in the control test vessel showed very slight corrosion in the scribes (Figure 11). The coated and scribed carbon steel coupons that were maintained above 95% R. H. did not show any corrosion when exposed to these VCIs for 9 months (Figures 12 and 13).



**FIGURE 11 - Coated and scribed steel coupon after 9 months exposure in control test vessel,
showing very mild corrosion in the scribes.**



**FIGURE 12 - Coated and scribed steel coupons after 9 months exposure to VCI A showing no
corrosion in the scribes**

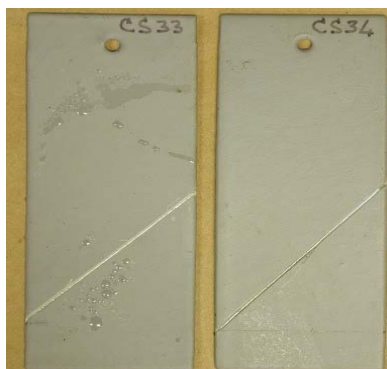


FIGURE 13 - Coated and scribed steel coupons after 9 months exposure to VCI B2 solution showing no corrosion in the scribes

Results of electrochemical testing

The results of Tafel scans obtained by electrochemical testing are summarized in Table 6 and Table 7. The results show the effect of 2% VCI A and 2% VCI B 2 when added to 0.1M NaCl solution.

The results of electrochemical (Tafel scan) testing showed that VCI B2 in 0.1M NaCl solution provided good corrosion protection for bare carbon steel. After 24 hours of standing, VCI B2 solution showed an inhibitor efficiency of 94% (Table 7) that increased to about 95% after 360 hours. For VCI A the efficiency after 24 hours of standing was at 69% efficiency and later on increased slowly to about 84% by about 528 hours of exposure. In 24 hours, in the case of VCI A in solution, a light red precipitate appeared and the red color slowly intensified as a function of exposure time until about 528 hours. In the case of VCI B2 solution, the electrolyte was clear until about 168 hours and later on, it turned to light red tinge without any precipitate formation.

Inhibitor efficiencies were calculated using corrosion rate data obtained by Tafel scan method when 2% VCIs were added to 0.1M NaCl solution. The inhibitor efficiencies of VCI A and VCI B2 in 0.1M NaCl for protecting bare carbon steel specimens are plotted versus time in hours in Figure 14. The efficiency of VCI A was at about 69% after 24 hours and then increases to about 81% in 48 hours, later on maintains its level of efficiency within +/- 3% deviation. The efficiency of VCI B2 starts at a higher level of 94% after 24 hours and maintains at approximately the same level with similar deviation. The efficiency trends of both VCI A and VCI B2 are similar in nature although when VCI B2 was added to 0.1M NaCl solution, it did not form any precipitation while VCI A formed a light red precipitate.

TABLE 6
TAFEL RESULTS FOR 1010 CARBON STEEL IN 0.1 M NaCl + 2% VCI A

Time of Exposure (hrs)	OCP (V) vs. Ag/Ag Cl	Anodic Slope (V/decade)x E⁻³	Cathodic Slope (V/decade)x E⁻³	Corrosion Rate (mpy)	Inhibitor Efficiency (%)	Remarks
0	-0.554	99.74	438.7	46.65	0	Control
0	-0.214	100.08	100.0	2.905	93.78	Turbid Solution
24	-0.695	126.3	218.1	14.46	69.0	Light red ppt.
48	-0.685	130.1	179.4	8.86	81.01	Light red ppt.
120	-0.688	110.1	372.2	10.06	78.43	Light red ppt.
144	-0.686	98.3	384.4	9.72	79.16	Light red ppt.
168	-0.700	105.1	442.9	11.3	75.77	Light red ppt.
192	-0.678	101.2	298.4	8.71	81.33	Light red ppt.
216	-0.685	109.6	317.0	9.21	80.26	Light red ppt.
288	-0.676	123.4	267.7	8.1	82.63	Light red ppt.
336	-0.689	133.9	285.1	7.97	82.91	Light red ppt.
360	-0.693	125.3	333.7	8.32	82.16	Light red ppt.
384	-0.698	118.5	338.2	8.04	82.76	Light red ppt.
456	-0.708	142.4	313.2	8.06	82.72	Light red ppt.
480	-0.708	135.6	333.7	7.88	83.11	Light red ppt.
528	-0.709	144.3	323.1	7.25	84.46	Light red ppt.

TABLE 7
TAFEL RESULTS FOR 1010 CARBON STEEL IN 0.1 M NaCl + 2% VCI B2

Time of Exposure (hrs)	OCP (V) vs. Ag/Ag Cl	Anodic Slope (V/decade) $\times E^{-3}$	Cathodic Slope (V/decade) $\times E^{-3}$	Corrosion Rate (mpy)	Inhibitor Efficiency (%)	Remarks
0	-0.554	99.74	438.7	46.65	-	Control
24	-0.294	236.1	336.5	2.67	94.27	Clear
48	-0.240	239.7	213.6	2.30	95.07	Clear
168	-0.236	443.1	319.7	4.80	89.71	Clear
216	-0.236	637.8	367.7	5.68	87.82	Light Red tinge
264	-0.258	404.5	175.4	2.56	94.51	Light Red tinge
336	-0.248	308.3	209.5	2.49	94.66	Light Red tinge
360	-0.262	362.6	138.4	2.18	95.33	Light Red tinge

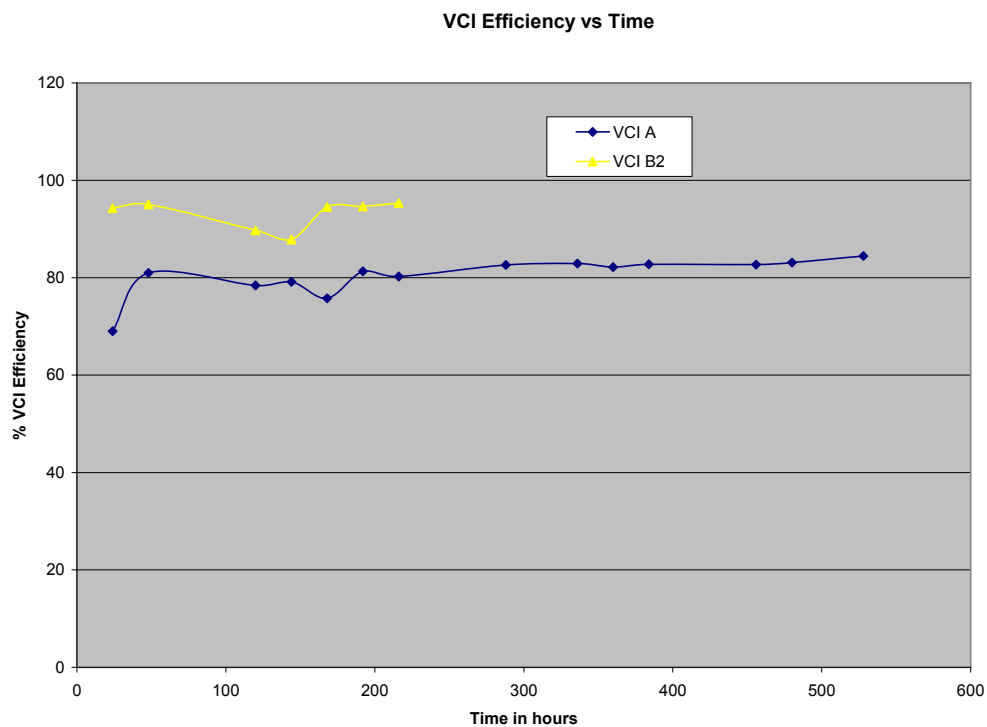


FIGURE 14 - Efficiency of VCI A and VCI B2 versus exposure time in hours

Follow-on Inspection of Shipboard Voids

A follow-on inspection of test voids will be conducted by the ship's force in October/November 2009, nearly 12 months after the installation of VCI A powder into selected voids. The results obtained will be documented in a future report or a paper.

CONCLUSIONS

In the coupon testing, VCI A powder showed better corrosion control than the other VCIs tested in protecting bare carbon steel coupons maintained above 95% R. H. and over a period of 9 month exposure. Bare steel coupons exposed to VCI B1 powder and VCI B2 solution spray and kept above 95% R.H. showed intermediate corrosion control; some of the coupons exposed to VCI B1 powder showed several corrosion spots possibly because of the lower dosage of VCI B1 powder. The steel coupons exposed to VCI B2 solution spray also showed spots of corrosion but lesser than the steel coupons exposed to VCI B1 powder. The coated and scribed carbon steel coupons that were maintained above 95% R. H. did not show any corrosion when exposed to these VCIs for 9 months. Only one of the coated and scribed steel coupons exposed in the control test vessel showed very slight corrosion in the scribes.

In electrochemical testing of bare steel coupons in 0.1M NaCl with 2% VCI added, VCI B2 showed a higher efficiency than VCI A. Additionally, the solution with VCI B2 remained clear with a light red tinge versus a formation of red precipitate in the case of VCI A in 0.1M NaCl solution. There was no correlation between coupon testing and electrochemical testing results. This can possibly be due to differences in VCI concentration used in the two testing methods.

FUTURE WORK

The effectiveness of the VCI installed into shipboard voids will be monitored for a period of two years and possibly more, and the results will be documented in future reports or papers.

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