

## Use of Volatile Corrosion Inhibitors in Packaging to Protect Equipment from Corrosion

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*Understanding environmental conditions experienced during shipping (both domestic and export) and/or storage is critical when determining the most effective corrosion control system for metal components. Temperature and humidity sensors were used to help understand the conditions within industrial packaging applications, during different overseas shipping routes, and during subsequent warehouse storage. The effect of secondary packaging (i.e., polyethylene film) on temperature and humidity within a package was also evaluated. The scope of this article is to compile and analyze the data, and utilize it to help develop the best corrosion prevention strategies.*

**Quantifying environmental conditions** experienced during shipment and storage of various metal components provides critical data, with respect to choosing the most effective preservation system. Differences in conditions can be seen as a shipment moves from port to open water, from a heated warehouse to an unheated truck, and also from the outside of the pack to the inside (i.e., box, crate, or within a piece of equipment). Analyses were made to evaluate these scenarios. Differences were evaluated inside the packaging systems, as well as from the outside to the inside of a system. These were used to gain insight into the efficacy of various corrosion-inhibiting systems, as well as the efficacy of adding a volatile corrosion inhibitor (VCI) to a given system.

### Laboratory Testing

Accelerated corrosion testing was performed for spare gear components used by a heavy equipment original equipment manufacturer (OEM), in preparation for a plant shutdown. The goal of this testing was to determine the efficacy of various packaging systems, while trying to also understand environmental conditions experienced within a given pack. The OEM wanted to be able to monitor conditions within its warehouse, and subsequently within each pack, in real time, over the course of the shutdown.

Gear components were wrapped in systems meant to simulate those used for shipment and storage. Temperature and humidity sensors were added to each pack, to quantify the effect of packing with a 50- $\mu$ m VCI polyethylene (PE) bag. All systems were then exposed to modified ASTM D1748<sup>1</sup> testing conditions for 185 h.

### Overseas Shipping

Environmental conditions during an overseas shipment can shift dramatically, from leaving port to crossing the equator. The daily rise and fall of temperature and humidity may not be as dramatic, but the overall trip from one side of the world to the other provides continuous challenges for nearly every industry. In this application, temperature and humidity sensors were placed inside two packages to evaluate the effect of differing packaging systems to control temperature and humidity swings within a cardboard container shipping components from the United States to China.

A second overseas shipping application examined the efficacy of VCI in protecting the internals of a steel fuel tank. The equipment OEM had been experiencing corrosion

issues during this shipment, due to the severe conditions experienced both during the shipment, and subsequent (indefinite) outdoor storage. Crawler units were sent from the United States to Brazil to compare treated and untreated fuel tanks. Temperature and humidity sensors were placed both inside the tank and to the frame of the crawler to measure the conditions experienced during shipment. Upon receipt, the tanks were opened and inspected for corrosion, to determine the efficacy of the VCI additive, and the sensors were recovered to review environmental data.

### Experimental Procedure

#### *Laboratory Testing— Modified ASTM D1748*

Test standard ASTM D1748 creates an accelerated corrosion atmosphere by combining high heat (48.9  $\pm$  1.1 °C [120  $\pm$  2 °F]) with constant condensing humidity and a steady rotation of test samples at  $\sim$ 0.33 rpm. Testing is performed for a predetermined period, or until such time that corrosion is observed on the metal surface.

In this evaluation, ASTM D1748 conditions were achieved with respect to temperature and humidity. However, due to the size and configuration of test parts and packaging, testing in true ASTM D1748 conditions was not feasible.

The goal of this test was twofold. The first goal was to evaluate the packaging system used for storage of component parts at the warehouse of a heavy equipment OEM. The existing packaging system was as follows:

- Sheet of plywood placed on a pallet
- Sheet of VCI paper on top of the plywood
- Layer of machined metal parts on the VCI paper

- Second layer of VCI paper on top of the metal parts
  - Second piece of plywood
- This system was repeated for multiple layers, at which point the entire pallet was wrapped in non-VCI stretch wrap.

For comparison, the corrosion-inhibiting efficacy of a 50- $\mu\text{m}$  VCI PE bag was evaluated. This bag would simulate a large over bag, serve as a pallet liner, and separate the metal part and VCI paper from the plywood. Specifically, the test system was as follows:

- Sheet of plywood
- VCI bag (bottom)
- VCI paper
- Metal part
- VCI paper
- VCI bag (top, folded over and closed, not heat-sealed or taped)
- Sheet of plywood
- Non-VCI PE stretch wrap

This system was compared to the current control system, as previously described, with a single gear component in each pack (Figure 1).

The second goal of the test was to track differences in temperature and humidity within the control pack vs. the pack with the 50- $\mu\text{m}$  VCI PE over bag. To accomplish this goal, temperature/relative humidity (RH) sensors were placed inside both packs during testing. Testing was run for 185 h, at which point the gear components were unwrapped, visually inspected, and photographed. Temperature and RH data were also collected from the sensors placed within the respective packs.

### Real World Analysis— Ocean Shipments

The first real world analysis involved a shipment of metal components from Illinois, United States to China. The process involved packing machined parts in small boxes. Each box was lined with 50- $\mu\text{m}$  non-VCI PE film, and within this film, parts were wrapped in VCI paper. Boxes were then bulk packed onto a pallet. The entire pallet of boxes would then be enclosed with a non-VCI PE shrink film. This system was compared to a second, less labor-intensive system, whereby the boxes were lined with VCI barrier paper, but no secondary bag. The entire pallet was covered with a non-VCI PE

bag. Within each pack, a temperature and humidity sensor was placed in one box (Figure 2). Conditions were logged for the duration of the 51-day shipment process.

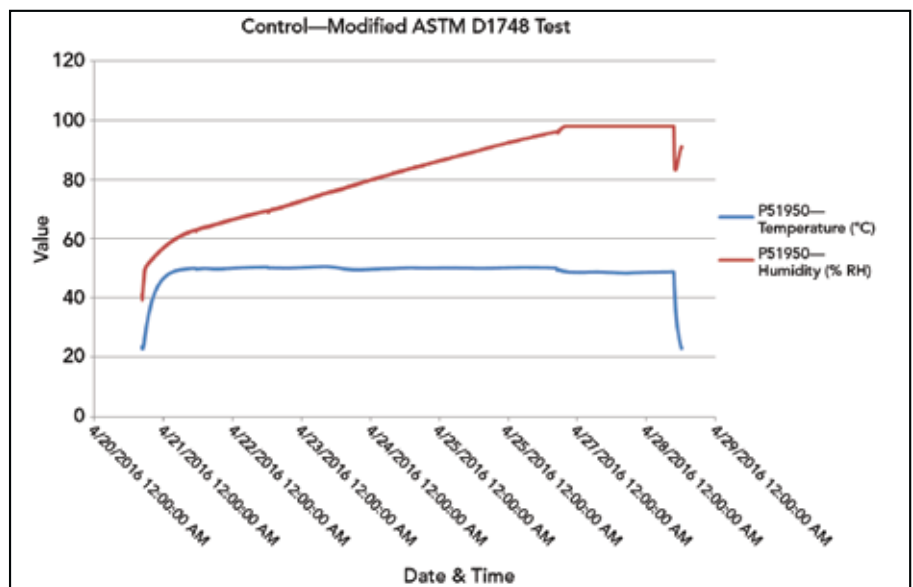
The second real world analysis involved evaluating temperature and humidity conditions experienced by crawler units shipped from Iowa, United States to Brazil. Two temperature and humidity sensors were placed on the crawler; one attached to a modified fuel cap, and a second attached to a hose on the vehicle exterior. The first sensor allowed for measurement of conditions experienced inside a partially filled biodiesel fuel tank, where the end user had been experiencing repeated corrosion problems during overseas shipment. Two crawlers were sent; one with standard biodiesel fuel, and the second



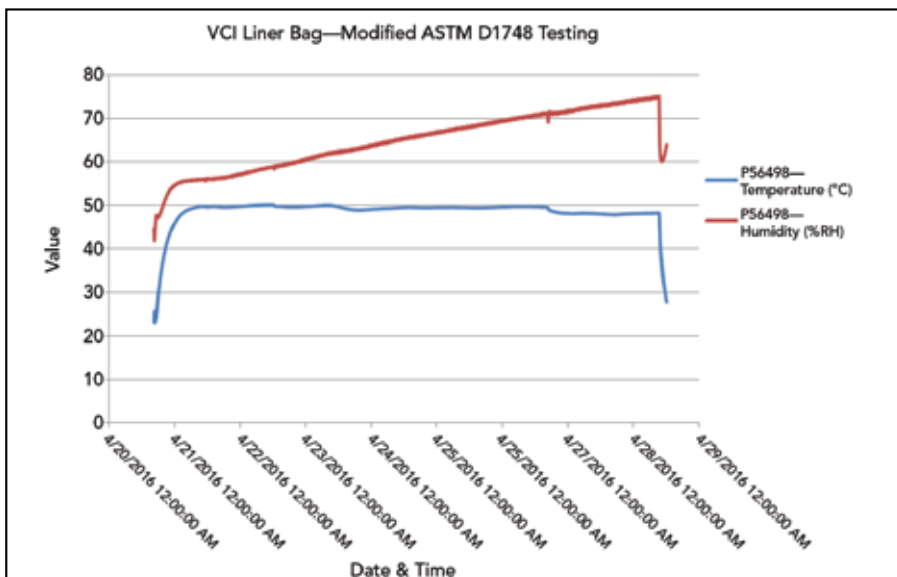
**FIGURE 1** Wrapped gear component prior to testing.



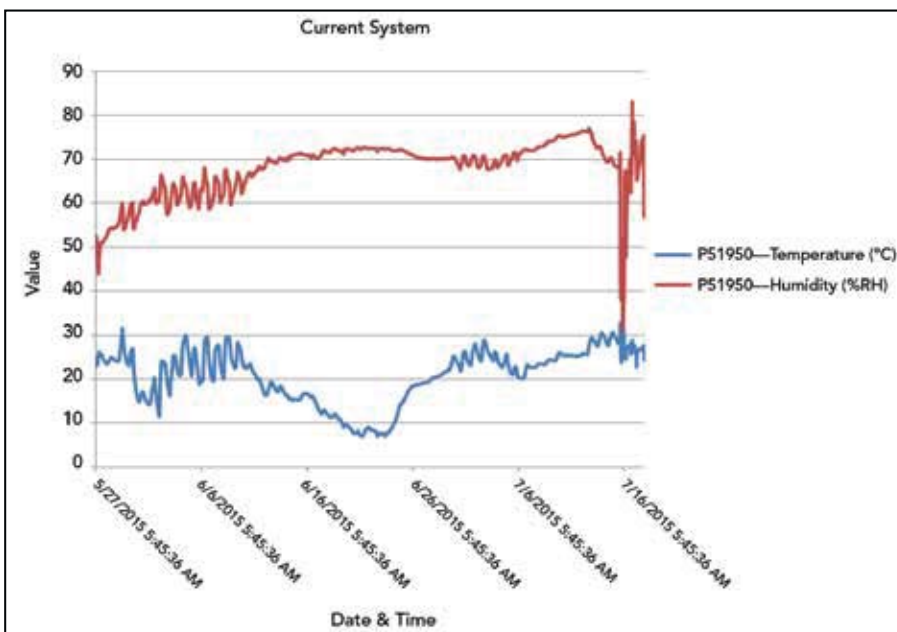
**FIGURE 2** Boxed parts prior to shipment, with sensor in place.



**FIGURE 3** Temperature and RH data from the control pack. In this pack, temperature reached 50 °C within 16 h. RH reached 75% in 62 h, and eventually reached 98%, where it remained for the final 36 h of testing.



**FIGURE 4** Temperature and RH data from the pack with 50- $\mu\text{m}$  VCI PE liner bag. Temperature reached 50 °C after 36 h, while RH reached a high of 75% at the end of testing.



**FIGURE 5** Sensor data from an overseas shipment, United States to China. The data above were the conditions within the control (current) end user system.

with a VCI additive (0.5% by tank volume) in the biodiesel. In addition to evaluating the conditions experienced in this shipment, the efficacy of the VCI additive was evaluated. It should be noted that only two sensors were available for this test. As such, both sensors were on/in the VCI-treated crawler.

## Results

### Laboratory Testing— Modified ASTM D1748

After 185 h of testing, the control part

showed significant corrosion, while the part packed with a 50- $\mu\text{m}$  VCI PE liner bag showed no corrosion.

When temperature and humidity data were reviewed, it was shown that both temperature and humidity increases were significantly slowed inside the pack with the 50- $\mu\text{m}$  VCI PE over bag. Whereas the internals of the control pack took 16 h to reach external testing conditions of 50 °C (Figure 3), the second pack took 36 h to reach 50 °C (Figure 4). When reviewing RH, the control pack reached 75% RH after 62 h of testing, and eventually

reached 98%, where it remained for the final 36 h of testing. Conversely, the pack with 50- $\mu\text{m}$  VCI PE over bag reached a high RH of 75% at the end of testing.

### Real World Analysis— Overseas Shipment 1

Average RH within the shrink-wrapped pallet was 68%, compared to 59% for the PE liner/bag covered pallet. The control pack exceeded 60% RH within four days, compared to 31 days for the PE liner/bag + VCI barrier paper system. Near the middle of the shipment, temperature dropped from 25 °C to 9 °C. During this time, the RH within the shrink-wrapped pallet did not change significantly (Figure 5). Conversely, changes in RH within the second pack closely followed temperature changes during this time, and throughout the rest of the shipment (Figure 6). This suggests that the individual PE bag may be trapping moisture inside. Corrosion was not seen in parts from either packaging system during this evaluation.

### Real World Analysis— Overseas Shipment 2

The two crawlers were shipped from Iowa, United States on September 2, 2016. They were sailed from port on September 6, 2016, at which point all readings showed daily fluctuations. The internal (fuel tank) sensor showed these fluctuations until September 16, whereas the external sensor continued to show fluctuations until September 21. Both crawlers arrived in Brazil on September 29, 2016. Initial inspection took place on October 20, 2016, at which time sensors were sent back to the United States for data collection. The external conditions continued to fluctuate during this time, whereas the internal readings stayed consistent until a few days before initial inspection.

Additionally, corrosion was found in the fill neck of the untreated tank upon receipt inspection. In the tank treated with VCI, no corrosion was found. For the purposes of this evaluation, exterior surface corrosion was not monitored.

## Conclusions

Use of temperature and humidity sensors can provide information critical to determining the most effective packaging and preservation methods for numerous storage and shipping applications.



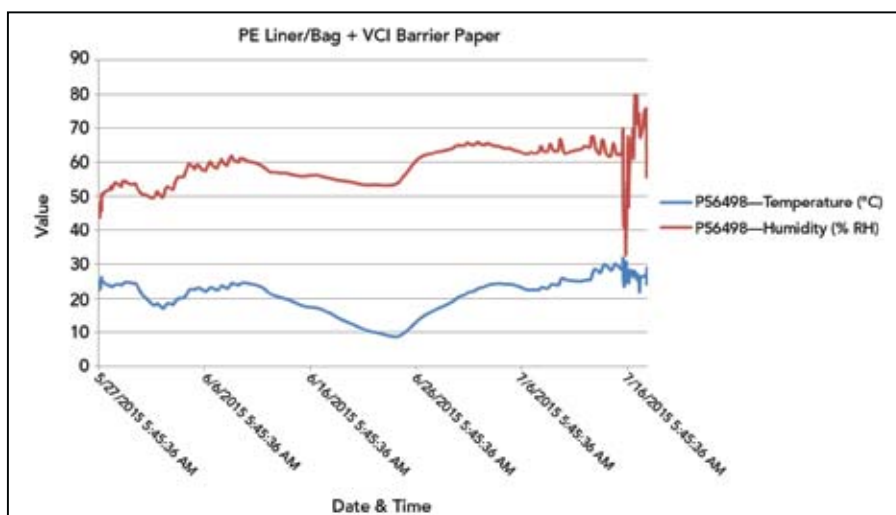
Laboratory testing, utilizing Modified ASTM D1748 conditions, showed that the use of a 50- $\mu\text{m}$  VCI PE liner bag reduced the RH inside a package by 23% after 185 h, from 98% to 75%. Further, a time to temperature increase to 50 °C inside the pack was slowed by more than 100%, from 16 h in the control pack to 36 h in the pack with an additional liner bag. This system also showed increased corrosion protection, compared to the control system, which only utilized VCI paper, stressing the importance of considering secondary VCI protection in some applications.

Two overseas shipments brought a variety of results. The first showed a significant reduction in RH exposure within a packaging system that utilized a combination of VCI barrier paper inside each box, non-VCI PE pallet liner, and over bag. This was compared to a control system where parts were wrapped in VCI paper and non-VCI PE bags in each box and the entire pallet being wrapped with PE shrink film. Although temperatures were constant among the two packs, the control pack reached and sustained an RH of 60% or greater within four days of shipment, compared to 31 days for the second pack. While corrosion was not seen in either of the tested packaging systems, the revised method would be less time-consuming and more cost effective. VCI paper would continue to be used, while eliminating the need for adding a PE bag to every individual box, and not requiring heat shrinking for every pallet.

The second overseas shipment explored differences in conditions experienced outside a large crawler unit, compared to conditions inside the fuel tank. Sensor readings showed that conditions on the vehicle exterior are much more severe, and also much more volatile, compared to inside the fuel tank. However, conditions within the fuel tank were still severe enough to induce corrosion during a six-week shipment and storage period, as seen in the untreated biodiesel tank. Conversely, a tank treated with VCI additive did not show any corrosion during this time (Figure 7). This fuel tank corrosion was the biggest concern of the end user, and combining the success of a VCI additive with the quantitative environmental data led to a change in preservation process prior to shipment.

## Acknowledgments

The authors would like to thank John



**FIGURE 6** Sensor data from an overseas shipment, United States to China. The data above were the conditions within a packaging system utilizing a PE liner and bag, plus VCI barrier paper.



**FIGURE 7** VCI-treated fuel tank after shipment. No corrosion was visible.

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## References

1. ASTM D1748 (latest revision), "Standard Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet" (West Conshohocken, PA: ASTM International).

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