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Utilizing Temperature and Humidity Sensors to Understand the Environmental Conditions of Export Packaging, and Utilizing this Data in Developing Corrosion Prevention Strategies

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ABSTRACT

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 paper is to compile and analyze the data, and utilizing it to help develop the best corrosion prevention strategies.

Key words: Sensor, corrosion control, packaging, overseas shipping

INTRODUCTION

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 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 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 their 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 micron VCI polyethylene (PE) bag. All systems were then exposed to modified ASTM(1) D1748[1] testing conditions for 185 hours.

Overseas Shipping

Environmental conditions during an overseas shipment can shift dramatically, from leaving port, to crossing the equator. 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 USA to China.

A second overseas shipping application examined the efficacy of VCI in protecting the internals of a steel fuel tank. The equipment OEM has 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 USA to Brasil, 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 +/- 1.1C, 120 +/- 2F) with constant condensing humidity, and steady rotation of test samples at ~0.33rpm. Testing is performed for a pre-determined 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 two-fold. 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:

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(1)ASTM International (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

-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 is 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 micron VCI PE bag was evaluated. This bag would simulate a large over bag, serving as a pallet liner, and to 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 described above, with a single gear component in each pack (Figure 1).

Figure 1: Wrapped gear component prior to testing.

The second goal of the test was to track differences in temperature and humidity within the control pack vs. the pack with the 50 micron VCI PE over bag. To accomplish this goal, temperature/relative humidity sensors were placed inside both packs during testing.

Testing was run for 185 hours, at which point the gear components were unwrapped, visually inspected, and photographed. Temperature and relative humidity 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, USA to China. The process involved packing machined parts in small boxes. Each box was lined with 50 micron non-VCI PE film, and within this film, parts were wrapped in VCI paper. Boxes were then bulk packed onto a pallet (Figure 2). 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 (Figure 3). Within each pack, a temperature and humidity sensor was placed in one box (Figure 4). Conditions were logged for the duration of the 51 day shipment process.

Figure 2: Boxes of parts stacked, prior to shipment.

Figure 3: Test packs, prior to shipment. Shrink wrapped pallet on the left, PE liner and bag on the right.

Figure 4: Boxed parts prior to shipment, with sensor in place.

The second real world analysis involved evaluating temperature and humidity conditions experienced by crawler units shipped from Iowa, USA to Brazil. Two temperature and humidity sensors were placed on the crawler; one attached to a modified fuel cap (Figure 5), and a second attached to a hose on the vehicle exterior (Figure 6). 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 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.

Figure 5: Temperature and humidity sensor attached to modified fuel cap.

Figure 6: Temperature and humidity sensor attached to hose on vehicle exterior.

RESULTS

Laboratory Testing – Modified ASTM D1748

After 185 hours of testing, the control part showed significant corrosion (Figure 7), while the part packed with a 50 micron VCI PE liner bag showed no corrosion (Figure 8).

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 micron VCI PE over bag. Whereas the internals of the control pack took 16 hours to reach external testing conditions of 50C (Figure 9), the second pack took 36 hours to reach 50C (Figure 10). When reviewing relative humidity, the control pack reached 75% relative humidity after 62 hours of testing, and eventually reached 98%, where it remained for the final 36 hours of testing. Conversely, the pack with 50 micron VCI PE over bag reached a high relative humidity of 75% at the end of testing.

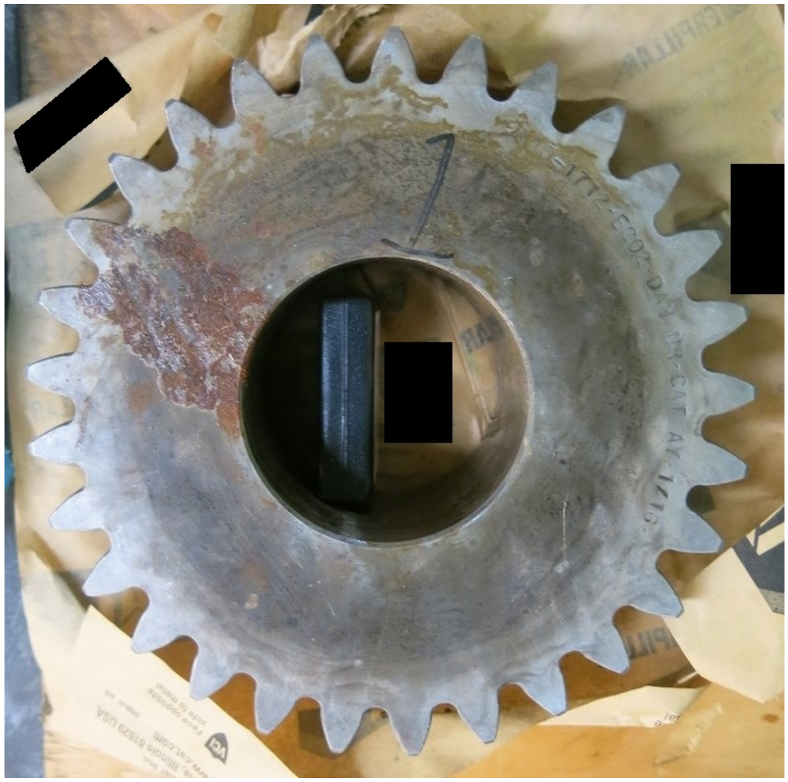

Figure 7: Control gear component, after 185 hours of Modified ASTM D1748 testing. Temperature and humidity sensor can be seen in the center of the picture, as located during the test. Severe corrosion can be seen on the left side of the gear component.

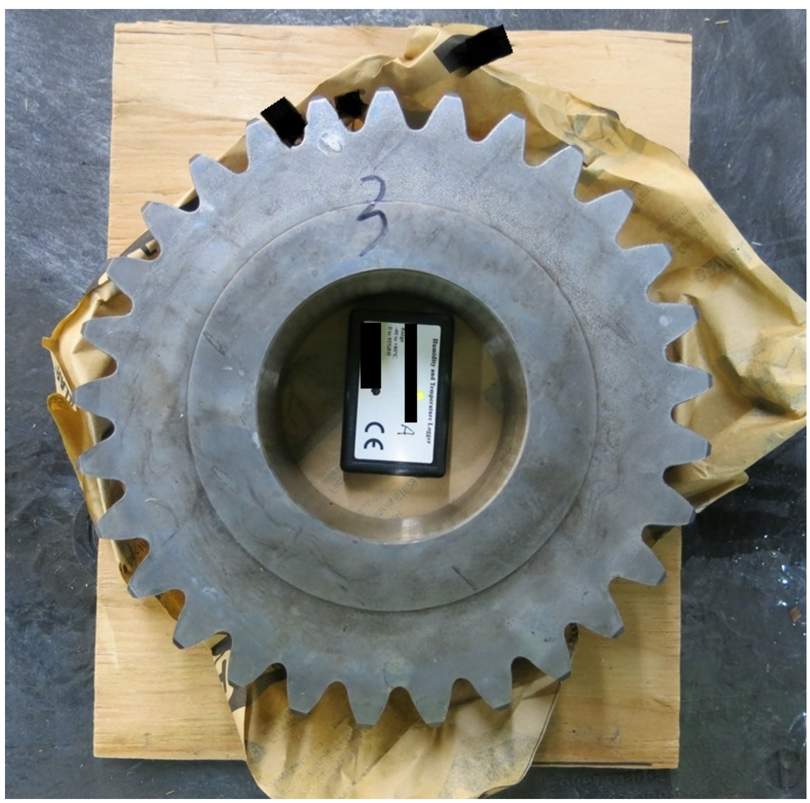

Figure 8: Second component, packed with 50 micron VCI PE liner bag, after 185 hours in Modified ASTM D1748 testing. Temperature and humidity sensor can be seen in the center of the picture, as located during the test.

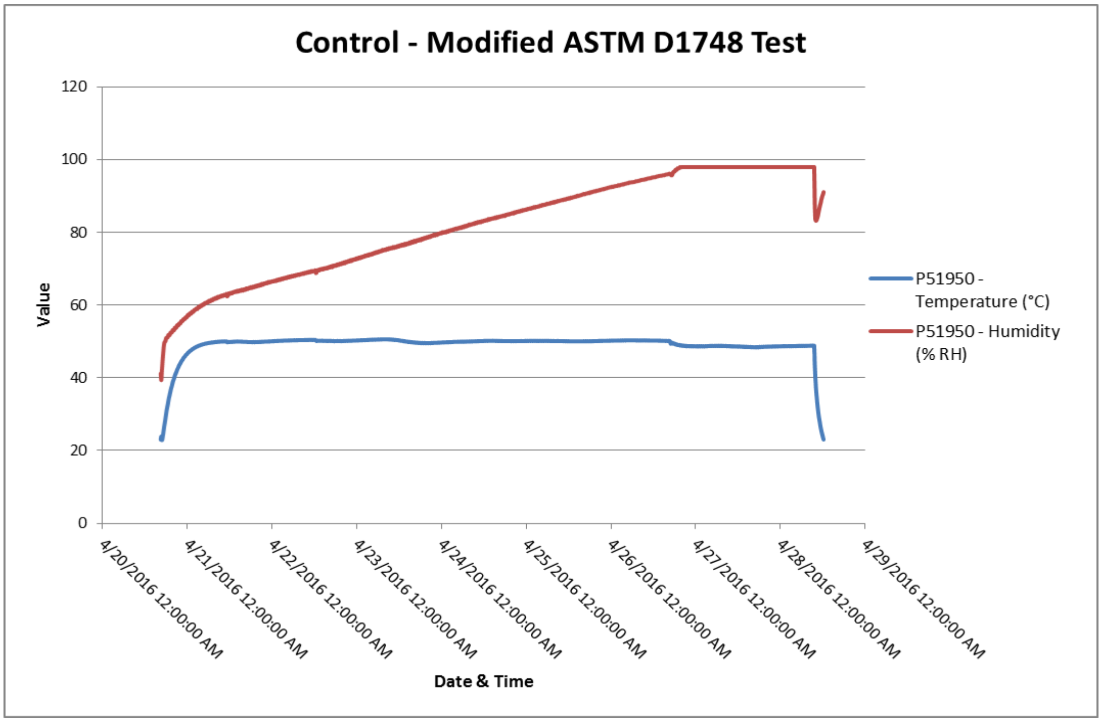

Figure 9: Temperature and relative humidity data from the control pack. In this pack, temperature reached 50C within 16 hours. Relative humidity reached 75% in 62 hours, and eventually reached 98%, where is remained for the final 36 hours of testing.

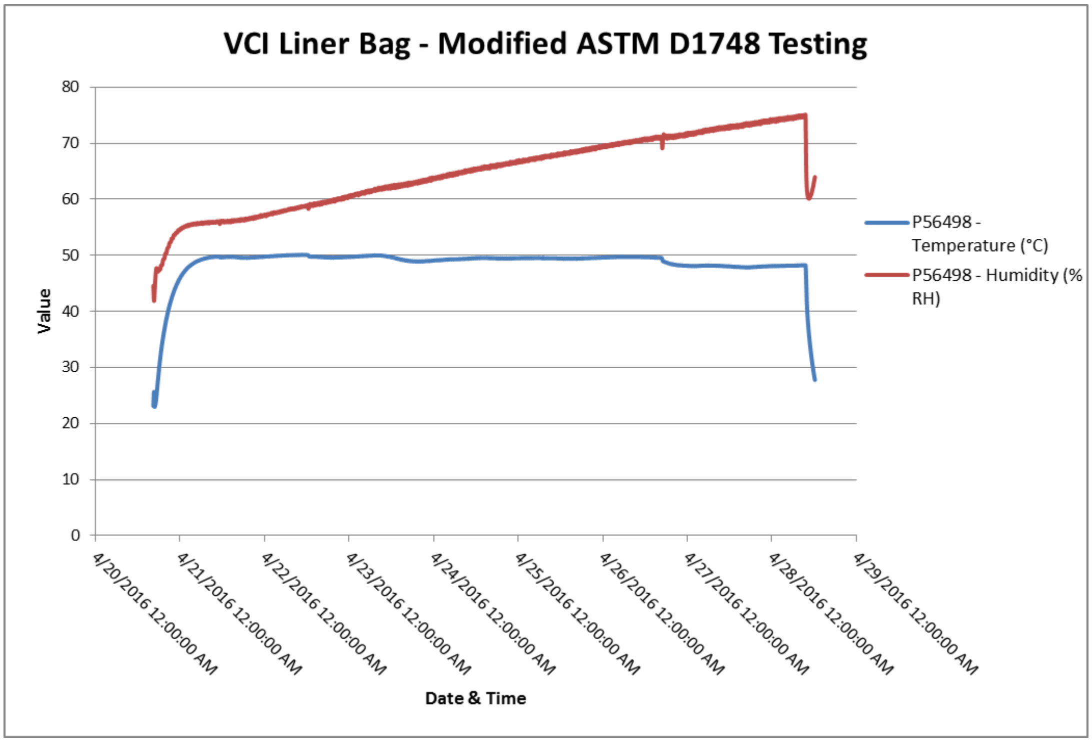

Figure 10: Temperature and relative humidity data from the pack with 50 micron VCI PE liner bag. Temperature reached 50C after 36 hours, while relative humidity reached a high of 75% at the end of testing.

Real World Analysis – Overseas Shipment 1

Average relative humidity within the shrink wrapped pallet was 68%, compared to 59% for the PE liner/bag covered pallet. The control pack exceeded 60% relative humidity within 4 days, compared to 31 days for the PE Liner/bag + VCI Barrier Paper system. Near the middle of the shipment, temperature dropped from 25C to 9C. During this time, the relative humidity within the shrink wrapped pallet did not change significantly (Figure 11). Conversely, changes in relative humidity within the second pack closely followed temperature changes during this time, and throughout the rest of the shipment (Figure 12). 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.

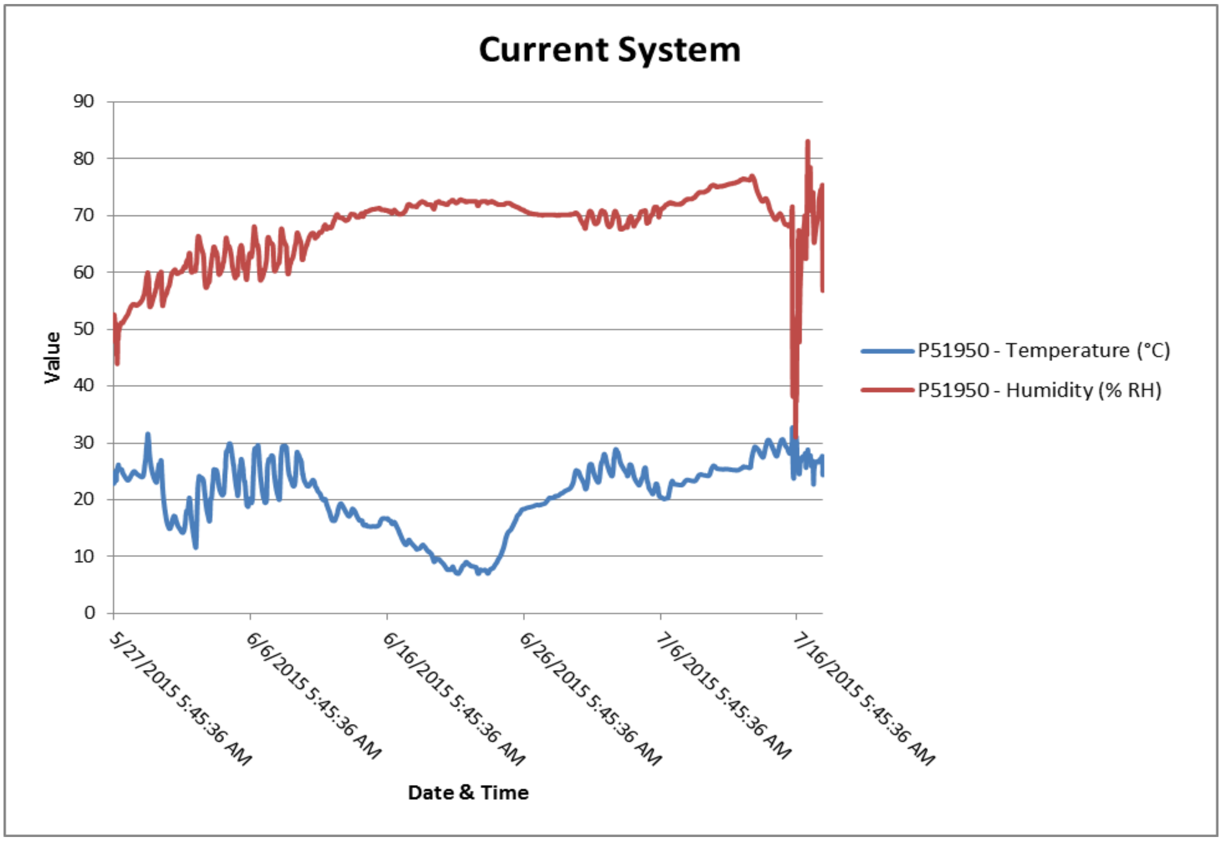

Figure 11: Sensor data from an overseas shipment, USA to China. The data above were the conditions within the control (current) end user system.

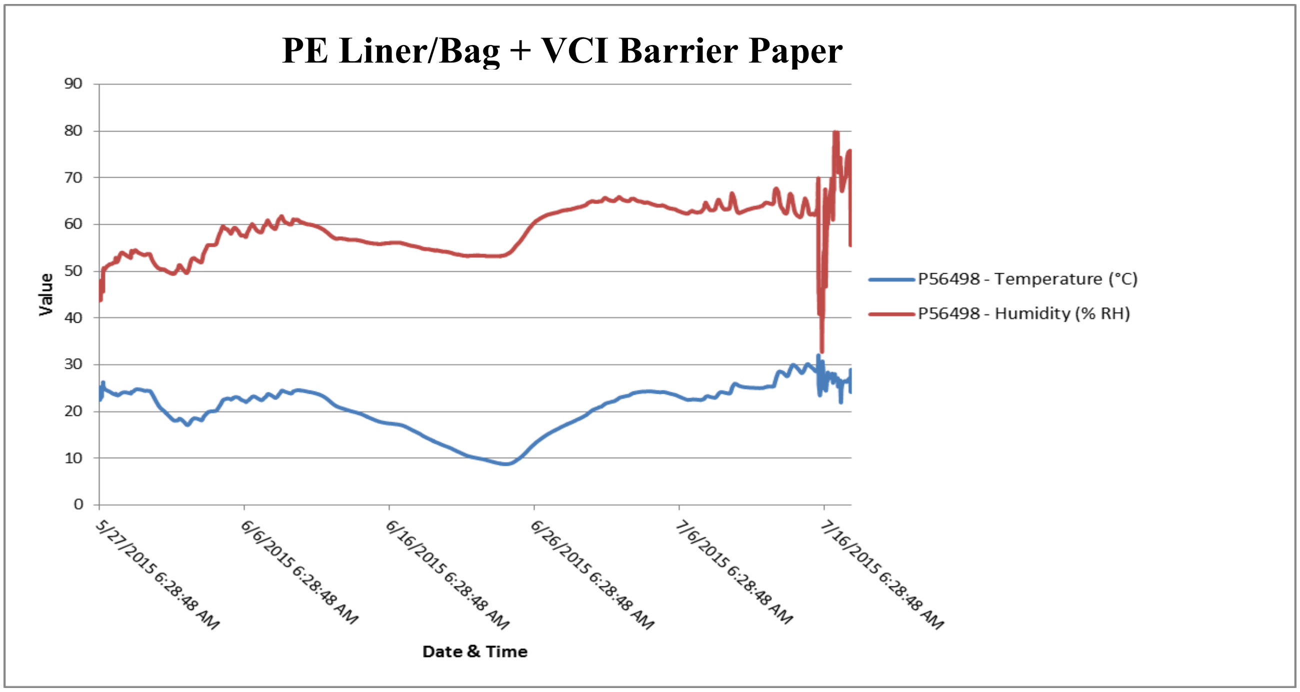

Figure 12: Sensor data from an overseas shipment, USA to China. The data above were the conditions within a packaging system utilizing a PE liner and bag, plus VCI Barrier Paper.

Real World Analysis – Overseas Shipment 2

The two crawlers were shipped from Iowa, USA on 2 September 2016. They were sailed from port on 6 September 2016, at which point all readings showed daily fluctuations. The internal (fuel tank) sensor showed these fluctuations until 16 September, whereas the external sensor continued to show fluctuations until 21 September. Both crawlers arrived in Brasil on 29 September 2016. Initial inspection took place on 20 October 2016, at which time sensors were sent back to the USA 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.

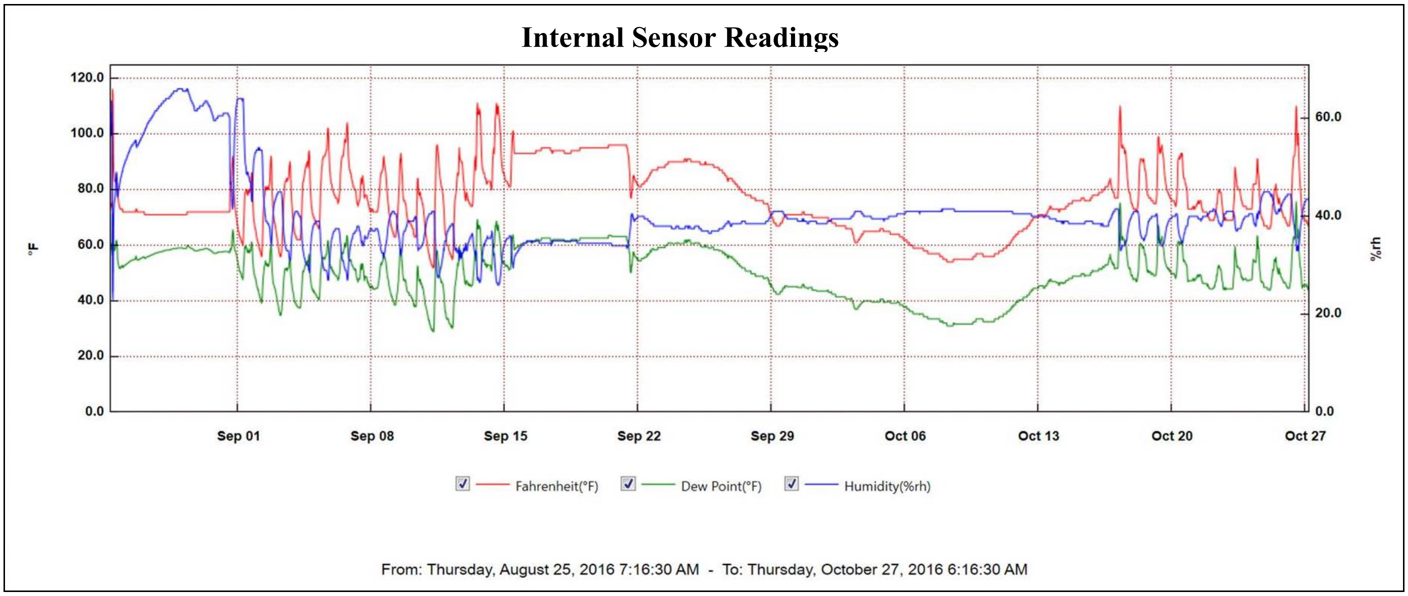

Figure 13: Internal sensor readings from overseas crawler shipment.

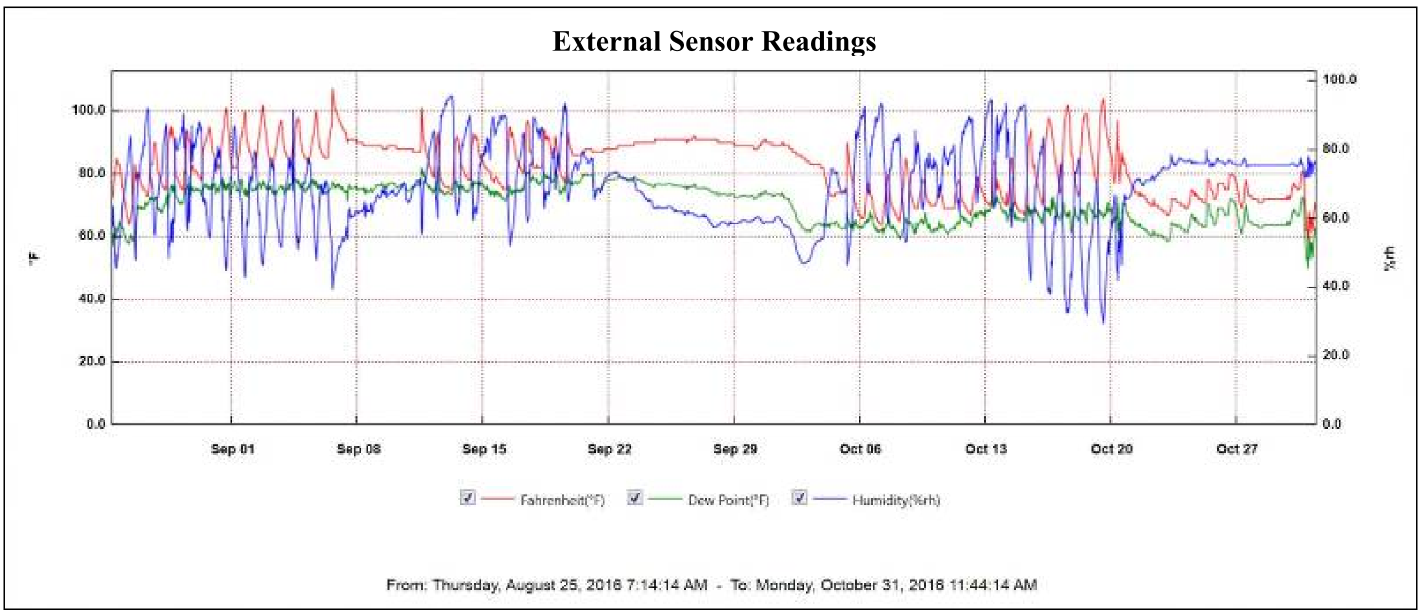

Figure 14: Internal sensor readings from overseas crawler shipment.

Figure 15: Untreated fuel tank, after shipment. Corrosion is present in the fill neck, which is commonly seen upon receipt inspection.

Figure 16: VCI treated fuel tank, after shipment. No corrosion was visible.

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 use of a 50 micron VCI PE liner bag reduced the relative humidity inside a package by 23% after 185 hours, from 98% to 75%. Further, time to temperature increase to 50C inside the pack was slowed by more than 100%, from 16 hours in the control pack to 36 hours 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 need for importance of considering secondary VCI protection in some applications.

Two overseas shipments brought a variety of results. The first showed a significant reduction in relative humidity 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 a relative humidity of 60% or greater within 4 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 6 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. 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 lead to a change in preservation process prior to shipment.

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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)