Effects of Chloride Contamination on the Performance of Tank and Vessel Linings

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It is now common knowledge that soluble salt contamination on a steel substrate can cause deterioration and early failure of linings in immersion service. As a result, the industry is giving more attention to the cleanliness of the metal substrate.

The most common characteristic of lining failures due to salt contamination is osmotic blistering. No organic lining is impermeable to water. Once it permeates the lining, water begins to dissolve the salt contamination at the steel/lining interface. This salt solution then develops an osmotic force, which attempts to draw more water into the blister to equalize the salt concentration to that of the immersion liquid.

Chlorides are the most common type of soluble salt contaminant and are the most problematic. Contamination can exist on new or used steel and can occur during transportation, storage, surface preparation, in-service exposure, hydrotesting, and tank cleaning. For this reason, all steel substrates should be checked for salt contamination before lining application.

Although the deleterious effects of salt contamination are well recognized, standards for surface cleanliness and maximum allowable chloride levels have not been agreed upon. This is because numerous variables can affect the threshold level at which chlorides will begin to cause lining failures. Wide ranges of threshold values have been reported, often without documentation of the variables used.

The chloride threshold is the highest level of chloride that a lining can tolerate for a particular service. Levels higher than the threshold will cause early failure of the lining. Levels lower than the threshold are tolerated by the lining. Unfortunately, we rarely know what the threshold value is for a particular lining in a particular service.

Threshold values can vary considerably, depending on the generic type of lining and its thickness. Other variables include the service temperature, the degree of cure or postcure, the type of immersion liquid, the amount of salts dissolved in an aqueous immersion liquid, the anchor profile, cold wall effects, and the type of soluble contaminants on the substrate. It is not surprising that there is so much difficulty in setting consensus standards.

This article reports on tests to determine the effects of chloride contamination on tank linings. Nine commercially available, ambient-cured, thin-film epoxy lining systems were evaluated for their tolerance to various levels of natural and artificially applied chloride contamination on steel substrates. The linings were tested by immersion in water or hydrocarbon/water at various temperatures for 13 and 6 months, respectively.

The first of three objectives of this study was to determine the chloride thresholds at various temperatures at which linings begin to fail. By determining and recommending those linings that have higher chloride thresholds, there will be a greater confidence that they can perform in a particular service. This is not to say that linings with higher tolerances should be used as a substitute for decontamination. Removal of chloride contamination is still highly recommended.

A number of reports in the literature have discussed various test methods to determine maximum allowable chloride levels. At issue is the manner in which the chloride is applied to the test panels. The second objective, therefore, was to compare two methods for applying the contamination. The methods are artifical and natural contamination.

Linings are often exposed to water and hydrocarbons. The third objective was to determine the effect on the chloride threshold levels when linings were immersed in a liquid containing both hydrocarbon and water. Answers to these questions would provide needed insight into the acceptable levels of chlorides for epoxy linings.

Experimental

Artificial Contamination Method

In this method, sodium chloride solutions were applied to non-corroded, abrasive-blasted steel panels. The panels were subsequently coated with one of nine different modified epoxy lining systems. After cure, the panels were immersed in tap water at various temperatures to determine the chloride threshold values at which blistering begins.

Surface Preparation for Panels Receiving Artificial Contamination

Panels were prepared using AISI #1018 carbon steel with dimensions of 3 in. x 6 in. x 1/4 in. (76 mm x 150 mm x 3 mm) thick. All panels were washed in the solvent methyl ethyl ketone before abrasive blasting. In all, 490 panels were abrasive blasted using a conventional outdoor blast unit with coal slag abrasive. Both sides were abraded to a Near-White
two coats using a conventional sprayer, as recommended by the manufacturer (Fig. 3). The immersion tests were initiated after a minimum of two weeks’ cure time at room temperature.

Natural Contamination Method
Although panels receiving natural contamination were prepared in the laboratory, the preparation technique is called the “natural method” to reflect the fact that the panels are corroded and pitted as if they were in real-time field exposures. This method gives a better simulation of the real manner in which chloride is distributed on the surface and within the pits.

In this method, panels were corroded in various levels of salt solution in a salt fog cabinet. The panels were then grit blasted and coated with six lining systems. After cure, the panels were immersed in tap water at various temperatures to determine the chloride threshold values.

Surface Preparation for Panels That Were Naturally Contaminated
Panels in this test were ANSI #1018 carbon steel with dimensions of 3 in. x 6 in. x 1/4 in. (76 mm x 150 mm, x 3 mm). They were initially grit blasted and coated with six lining systems. After cure, the panels were immersed in tap water at various temperatures to determine the chloride threshold values.

Uniformity of Chloride Application
To test the uniformity of salt application over the entire panel, three panels were contaminated, as described above, on one side only, at a nominal level of 33.5 µg/cm². Each panel was then cut into 18 one-inch (25-millimeter) squares with a band saw. Each square was extracted with 10 ml of deionized water for several hours at 130 F (54 C). The chloride concentrations in the extracts were quantified by chloride-specific electrode, and the dimensions of each square were measured with a micrometer. Based on the area of the squares and the amount of chloride in the extract, the chloride levels in µg/cm² were determined for each square.

Lining Application
Nine commercially available lining systems noted in Table 1 were applied to the artificially contaminated panels in SSPC-SP 10 cleanliness and a surface profile of 2.9–3.0 mils (74–76 microns).

Application of Artificially Contaminated Chloride
Various concentrations of sodium chloride were prepared in solutions of ethanol (80% by volume) and water (20% by volume). Each solution was applied as uniformly as possible onto the panels using a volume of 500 microliters (µl) per panel. The chloride applications ranged from 0–30 micrograms (µg) chloride/cm². (See Tables 3a-3c for actual levels for each lining.) For each panel, both sides were contaminated at the same level and tested. There were ten chloride levels for each lining system at each immersion temperature. The tests were conducted at five or seven immersion temperatures ranging from 75–190 F (24–88 C).

Prior to application of the salt solutions, the panels were warmed to 130 F (54 C). Then 500 µl of the salt solution was applied and immediately spread evenly over the entire panel with a ¾-in. (9.5-mm) outside diameter (OD) glass rod (Fig.1). The glass rod was continuously wiped (but not rotated) over the panel to keep the solution uniformly distributed until the liquid dried (Fig. 2). Then a gentle stream of dry, compressed air was blown over the panel to remove residual moisture.

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Five randomly selected grit-blasted panels from each of the five salt fog exposures were extracted to quantify the chloride levels for each set. The extractions were performed in boiling deionized water for one hour and quantified by ion exchange chromatography. The average chloride contamination for each set was determined as shown in the box below.

The chloride levels for the 0.5 and 5% exposures did not correlate well to other sets. There was a greater level of chloride for the 0.5% exposure than for the 5% exposure. It is believed that in an attempt to bring the panels back to a

### Average Chloride Contamination for 5 Grit-Blasted Panels from Each Set

<table>
<thead>
<tr>
<th>Salt Fog Level (% NaCl in water)</th>
<th>0</th>
<th>0.25</th>
<th>0.5</th>
<th>1.0</th>
<th>2.5</th>
<th>5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Chloride Level on Panel (µg/cm²)</td>
<td>&lt;0.2</td>
<td>0.6</td>
<td>5.3</td>
<td>3.9</td>
<td>7.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Standard Deviation ± (µg/cm²)</td>
<td>---</td>
<td>0.1</td>
<td>1.1</td>
<td>2.1</td>
<td>2.8</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Near-White cleanliness, the panels from the 5% exposure received a greater degree of abrasive blasting than the other sets and that the panels from the 0.5% exposure received a lesser degree of cleaning. This would account for the different degrees of flash rust that had developed on each set. Thus, all panels were abrasive blasted twice, and the flash rust was removed on the second blast.

### Uniformity of Chloride Application

Three grit-blasted panels from the 5% NaCl salt fog exposure were tested for uniformity of chloride distribution in the same way as the artificial set was tested. These panels were abrasive blasted only once, cut into 18 one-inch (25-millimeter) squares, and extracted. The chloride content was quantified by a chloride-specific electrode. Due to constraints on time and materials, only six lining systems were used to evaluate the natural contamination method.

### Panel Preparation for Testing in Water/Gasoline

This test was performed to determine the effects on the chloride threshold when a hydrocarbon was added to the water. Panels were cleaned and abrasive blasted as noted above for the artificial contamination method. Several levels of chloride contamination were applied to the panels using the artificial application method. Four lining systems were tested.

### Immersion Testing

#### Tap Water Immerisons

After a two-week cure time at ambient temperatures, the artificially and naturally contaminated panels were immersed in tap water ranging from 75–190 F (24–88 C) as shown in

#### Tap Water/Gasoline Immersions

Panels in this test were also cured for two weeks at ambient temperatures. This test also used one panel per chloride level. The panels were immersed upright with the top half of the panel in the gasoline phase and the bottom half in water. The gasoline contained 10% methyl tertiary butyl ether. The test temperature was 130 F (54 C), and the test duration was six months.

### Results and Discussion

#### Uniformity of Chloride Application

It is important to obtain an even distribution of chloride across the panel. If the distribution is very uneven, then there could be areas containing chloride levels that are significantly greater than the nominally applied values. If blistering occurs in these regions, it may not be representative for the nominal values being tested.

It was believed that an acceptable level of deviation from the nominal value was about ±10%. For the naturally contaminated panels, 7 out of 18 squares, or 39% of the area, exceeded the maximum deviation level.

For the artificial application of chloride, only 3 out of 18 squares for each panel contained levels that exceeded the maximum deviation. Three squares amounted to about 20% of the total area on one side of a panel. This variability of the chloride levels within panels receiving the artificial application may have been a result of very slight warpage of the panels during abrasive blasting. Depending on how a panel was warped, there may have been more or less salt deposited in the center compared to the edges. It is possible that in future tests, this variability can be lowered by using thicker panels, i.e., ¾₄ in. (5 mm) or ¾₄ in. (6 mm), which would be less susceptible to warpage.

This demonstrates that artificial contamination provides a more uniform distribution of chloride and should be the method of choice for studying the effects of salt contamination on coatings and linings.

From the tests with the artificially contaminated panels, it seems reasonable to disregard any blistering up to 20% of the area of the panel. Any blistering that exceeds 20% of the area should then be a result of the nominally applied value. Consequently, lining failure for the artificial application method was defined as blistering that was greater than 20% of the area on any one of the two sides tested. Linings were also considered to have failed if there were more than five blisters or cracks scattered over the face of the panel. Cracks and blisters along the edges were not counted.
With the greater variability of the naturally contaminated panels, it was thought that failure should be defined as blistering greater than 40% of the area on either of the two sides of a panel.

Lining Application
The average thicknesses for each lining system are listed in Table 1. All of the average thicknesses were within or very close to the desired dry film thickness.

Threshold Limits for Artificially Contaminated Panels
The results are shown in Tables 2 and 3a-c and Fig. 4. In this study, the threshold level was defined as the maximum chloride level at a given temperature for which the lining was still considered passing. The chloride threshold levels for all but one system decreased with increasing temperatures. Lining #4 did not follow this trend, since the thresholds increased in the temperature range of 110–170 F (43–77 C). One possible explanation is that this lining developed a higher degree of “postcuring” at the higher immersion temperatures than at the lower temperatures. This greater postcuring could impart greater water resistance and better wet adhesion for the lining, resulting in a higher chloride tolerance.

There were significant differences among the threshold values of the linings at a given temperature. The values ranged from approximately 4–20 µg/cm² at 75 F (24 C). (Some of the values for 90 and 75 F [32 and 24 C] in Table 2 were determined by extrapolation.) This demonstrates that even within the same generic type, there are considerable differences in tolerances to chloride contamination.

Another way to view these results is to look at the effect of increasing levels of contamination on the maximum service temperatures of a lining. As noted in Fig. 4, even levels of 1 µg/cm² can affect the lining’s performance. On the average, each additional microgram lowered the maximum service temperature of the lining by about 10 degrees F (6 degrees C).

My company currently sets the maximum allowable chloride level at 5 µg/cm² for ambient temperature immersion service. Three of the nine lining systems evaluated here might have failed if the steel substrate were contaminated at the maximum allowable level of 5 µg/cm².

The data also suggest that linings having higher maximum service temperatures (MST) will also have higher chloride threshold values for a given temperature (Fig. 4). The MST may be interpreted as the temperature at which the curve intersects the X axis at 0 µg/cm². For example, lining #8 in Fig. 4 appears to have the highest MST, well over 200 F (93 C), and has the highest threshold values compared to the other 8 linings. For the other linings, the lower the MST, the lower the threshold values.

A draft ISO document1 reported the maximum acceptable chloride levels from 11 lining manufacturers for immersion service. The levels ranged from 1 to 10 µg/cm² with an average of 5 µg/cm². The work described in this report also tends to support a maximum allowable chloride criterion of about 4–5 µg/cm² for ambient temperature immersion service when no other critical factors are involved. As service temperatures are increased, this criterion should be progressively lowered.

As noted in Tables 3a-c and 5, the linings with the highest chloride levels at a given temperature generally failed first. This was followed by progressively longer failure times for the lower chloride levels. The longest failure time for a

### Table 1: Thicknesses for Linings Evaluated in This Study

<table>
<thead>
<tr>
<th>Lining #</th>
<th>Type Lining</th>
<th>Avg Actual DFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EN</td>
<td>12.6</td>
</tr>
<tr>
<td>2</td>
<td>EP</td>
<td>7.6</td>
</tr>
<tr>
<td>3</td>
<td>EP</td>
<td>9.4</td>
</tr>
<tr>
<td>4</td>
<td>EN</td>
<td>10.3</td>
</tr>
<tr>
<td>5</td>
<td>EP</td>
<td>10.1</td>
</tr>
<tr>
<td>6</td>
<td>EP</td>
<td>10.1</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
<td>10.8</td>
</tr>
<tr>
<td>8</td>
<td>EP</td>
<td>10.7</td>
</tr>
<tr>
<td>9</td>
<td>EP</td>
<td>18.4</td>
</tr>
</tbody>
</table>

Lining type: E: epoxy, EN: epoxy novolac, EP: epoxy phenolic

### Table 2: Summary of Threshold Limits for Artificially Contaminated Panels after 13 Months of Immersion in Tap Water (µg chloride/cm²)*

<table>
<thead>
<tr>
<th>Lining</th>
<th>190 F</th>
<th>170 F</th>
<th>150 F</th>
<th>130 F</th>
<th>110 F</th>
<th>90 F</th>
<th>75 F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>7.5</td>
<td>15</td>
<td>&gt;20</td>
<td>&gt;20</td>
<td>(&gt;20)*</td>
<td>(&gt;20)*</td>
</tr>
<tr>
<td>2</td>
<td>F at 0</td>
<td>F at 0</td>
<td>4</td>
<td>5</td>
<td>7.5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>F at 0</td>
<td>F at 0</td>
<td>F at 0</td>
<td>F at 0</td>
<td>2</td>
<td>(3) (4)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>F at 0</td>
<td>&gt;20</td>
<td>10</td>
<td>10</td>
<td>7.5</td>
<td>(6) (4)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>F at 0</td>
<td>F at 0</td>
<td>F at 0</td>
<td>2</td>
<td>3</td>
<td>(3) (4)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>F at 0</td>
<td>F at 0</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>F at 0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>(6) (7)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>17.5</td>
<td>15</td>
<td>20</td>
<td>17.5</td>
<td>22.5</td>
<td>&lt;120</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>F at 0</td>
<td>F at 0</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>7.5</td>
</tr>
</tbody>
</table>

*Threshold limits in parenthesis in the 90 and 75 F columns are extrapolated values. F at 0 means that the lining failed even though no salt contamination was applied; in other words, the maximum service temperature of the lining was exceeded.
given temperature occurred just above the threshold value. Nevertheless, these failure times (just above the threshold value) still ranged from 2–43 weeks and surprisingly did not depend on temperature. There were short failure times at low temperatures as well as at high temperatures.

Another observation is the degree of blistering above and at the threshold levels. Almost all of the samples at the threshold had no blistering. A few ranged from 0–20% of the area, and the average was 2%. At the first chloride level above the threshold, the samples had a significant increase in the amount of blistered area. The average percentage of area for these samples was 46%. So there was a clear transition at the chloride threshold level that was easy to identify.

After ten months’ immersion, the panels containing chloride levels at the threshold level were tested for the degree of adhesion of the linings. Observations were also made for the degree of corrosion on the steel under the coating. In 38 out of 40 samples, the steel was still a gray to dark gray color. The adhesion values were all good.

In previously unreported work performed by my company on a similar study, linings with salt levels below the threshold have shown no significant deterioration after 23 months’ immersion. Therefore, it appears that linings do not undergo significant long-term deterioration for chloride levels at or below the threshold. As a result, an immersion test duration of 10 months should be sufficient to determine threshold values for most thin film linings.

Threshold Limits for Naturally Contaminated Panels

The chloride threshold values were determined for six lining systems at five levels of chloride contamination and at five temperatures (Table 5). These values were then compared to the values obtained for artificially contaminated test panels (Table 4).

The purpose of the comparison was to determine how similar the threshold values are for the two contamination methods. In the artificial contamination method, a known amount of chloride is uniformly applied onto the panels before coating application. The advantages of this method are relative ease of preparation, known levels of contamination, and a more uniform distribution over the panel.

The natural method is more realistic because the panels are first corroded in a salt fog cabinet. This method is a better simulation of the real nature of corroded steel because the panels include micropits and ferrous/ferric types of chloride salts. However, it is much more difficult to make the naturally corroded panels and to quantify the chloride levels on them. There is also greater variability of the chloride levels on these panels. One reason for the high degree of variation on these panels is the difficulty in providing uniform grit blasting of the corroded panels, both within the panel and from panel to panel.

If the thresholds are similar for the two methods, then this justifies the sole use of the artificial method for determining the salt tolerance of a lining.

Threshold values could not be determined for linings 1 and 4 because the thresholds at all temperatures were above the highest contaminant level on the test panels. For the four other linings, the trends followed those for the artificially contaminated panels. As the temperature increased, the threshold values decreased.

In general, there were two differences between results for the two methods. The natural contamination method gave...
thresholds that were slightly higher than for the artificial method. But this occurred only in the 110–150 F (43–66 C) range (Table 4). Because the differences in threshold values were minor, the two methods may be considered to give similar results. The second difference was the times to failure for the naturally contaminated panels. They were longer in the 110–170 F (43–77 C) range than for corresponding panels prepared with the artificial method (Tables 3a-c and 5).

Because the artificial method gives slightly lower thresholds for linings, it can be thought of as slightly more conservative compared to the natural contamination method. The more conservative thresholds are actually desirable. In the real world, there are a number of other factors (not included in this test) that tend to lower the chloride threshold values.

### Table 3b: Time to Failure by Blistering for Linings Applied on Artificially Contaminated Panels*

<table>
<thead>
<tr>
<th>Applied Salt Level (µg/cm²)</th>
<th>Lining #4</th>
<th>Lining #5</th>
<th>Lining #6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time to Blistering (Weeks) at Various Temp. (F)</td>
<td>190</td>
<td>170</td>
</tr>
<tr>
<td>7.5</td>
<td>43-56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
<tr>
<td>10</td>
<td>43-56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
<tr>
<td>15</td>
<td>43-56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
<tr>
<td>20</td>
<td>43-56</td>
<td>&gt;56</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* Samples that have not failed at the 13-month observation are marked with the "greater than" (>) sign.

### Table 3c: Time to Failure by Blistering for Linings Applied on Artificially Contaminated Panels*

<table>
<thead>
<tr>
<th>Applied Salt Level (µg/cm²)</th>
<th>Lining #7</th>
<th>Lining #8</th>
<th>Lining #9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time to Blistering (Weeks) at Various Temp. (F)</td>
<td>190</td>
<td>170</td>
</tr>
<tr>
<td>7.5</td>
<td>&gt;56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
<tr>
<td>10</td>
<td>&gt;56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
<tr>
<td>15</td>
<td>&gt;56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
<tr>
<td>20</td>
<td>&gt;56</td>
<td>&gt;56</td>
<td>&gt;56</td>
</tr>
</tbody>
</table>

* Samples that have not failed at the 13-month observation are marked with the "greater than" (>) sign.
gard to chloride tolerance of linings, it would be appropriate for owners to set performance criteria for lining products. Linings, for example, could be specified to withstand particular chloride levels for a given service.

It is recommended that the artificial contamination method be used to compare the chloride tolerance levels of commercially available linings. The use of this test is highly recommended for services at higher temperatures where contaminated steel is likely.

A combination of proper surface cleaning and the use of linings with greater tolerance to chlorides should result in a longer lifetime for the lining system. At 130 °F (54 °C), five of the nine linings tested would fail if a metal substrate had 5 µg chloride/cm² on the surface. So the tolerance of the lining to chloride contamination should be a factor in the choice of a lining.

**Threshold Limits for Linings Immersed in Gasoline/Water**

The addition of an organic or hydrocarbon phase such as gasoline appears to lower the chloride threshold for linings compared to immersion in water only. For three out

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**Table 4: Comparison of Chloride Threshold Values for Naturally and Artificially Contaminated Panels (µg chloride/cm²)**

<table>
<thead>
<tr>
<th>Lining</th>
<th>Naturally Contaminated Panels*</th>
<th>Artificially Contaminated Panels**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>190 F</td>
<td>170 F</td>
</tr>
<tr>
<td>2</td>
<td>F at 0</td>
<td>F at 0</td>
</tr>
<tr>
<td>3</td>
<td>F at 0</td>
<td>F at 0</td>
</tr>
<tr>
<td>5</td>
<td>F at 0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>F at 0</td>
<td>1</td>
</tr>
</tbody>
</table>

*This is a summary of data taken from Table 5.

**This is a summary of data taken from Table 3.

F at 0 means that the lining failed even though no salt contamination was applied; in other words, the maximum service temperature of the lining was exceeded.

Examples are less than optimum abrasive blasting cleanliness and profile, cold wall effects, and insufficient cure.

Also, when quantifying chloride on steel, most tests extract only about 50% of the chloride, so there is an underestimation of the chloride on the steel. Therefore, it is desirable to use the artificial method, which gives more conservative results.

Knowing there is a wide range of performance with regard to chloride tolerance of linings, it would be appropriate for owners to set performance criteria for lining products.
immersions are also at the 6-month immersion times. For purposes of direct comparison, the results for the water
*The duration of the gasoline/water immersion was 6 months.

Samples that have not failed at the 13-month observation are marked with a “greater than” (>) sign.

For elevated service temperatures, even 1 µg/cm² has an effect that lowers the nine different modified epoxy linings. For elevated service
ied considerably (about 4–20 µg/cm² at 75 F [24 C]) for
These results demonstrate that chloride threshold levels var-
atures increase, there is a decrease in chloride tolerance. The
natural contamination method was found to have slightly
higher tolerances for chloride in the 110–150 F (43–66 C)
range and longer times to failure than for the artificial
method. However, the use of the artificial method is a more
acceptable method for comparing salt tolerances of linings.
It gives a slightly more conservative evaluation of perfor-
mance, is easier to prepare, and has a more uniform distrib-
ution of chloride over the panel.
Most but not all the linings used in the gasoline/water
immersions were found to have lower thresholds for chlo-
ride than for immersions in water only. For linings exposed
to hydrocarbons and water, it is recommended that owners
make a careful evaluation of the service conditions to deter-
mine acceptable levels of chloride. In many cases, especially
at elevated temperatures, the maximum allowable amounts
could be non-detectable levels.

### Conclusion

These results demonstrate that chloride threshold levels varied considerably (about 4–20 µg/cm² at 75 F [24 C]) for
different modified epoxy linings. For elevated service
temperatures, even 1 µg/cm² has an effect that lowers the
maximum service temperature of the lining by about 10 de-
grees F (6 degrees C). Also, there does not appear to be a
significant long-term deterioration for chloride levels at or
below the threshold level.

Both methods for applying salt contamination (artificial
and natural) give a similar trend: as immersion tempera-
tures increase, there is a decrease in chloride tolerance. The
natural contamination method was found to have slightly

### Reference

1. ISO Draft #15235, British Standards Institution, Preparation
of Steel Substrates Before Application of Paints and
Related Products, Nov. 12, 1999.

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