Every year more than $10 billion dollars\(^1\) is spent remediating electrical utilities, petrochemical and petroleum refinery equipment that has been compromised by corrosion. This also includes costs associated with down time, lost product and production and in the worst of cases, worker safety. Material selection for industrial insulation is based on a number of factors such as thermal performance, fire resistance and linear shrinkage. In the case of Corrosion Under Insulation (CUI), consideration should also include how the insulation responds to moisture and the insulation's potential for corrosion. Production facilities need to be mindful of corrosion and solutions that exist to help manage, if not eliminate, the potential for CUI.

CUI in piping systems generally occurs when water is introduced to the insulation system by flooding, ground water, rainfall, humidity, spray from deluge systems or fire sprinklers, leaks in piping, valves and flanges or compromised jacketing. The water contaminating the system will most likely contain chlorides, even for a fresh water contamination such as rain. As the water enters the system and interacts with the insulation, any contaminants in the insulation can be picked up. When the contaminated water reaches the surface of the pipe, the mixture facilitates corrosion by allowing the corrosive element to interact with the surface of the piping. How quickly the pipe corrodes depends on the temperature of the pipe, the concentration of contaminants and the length of time the system is exposed to water. Pipe temperatures ranging from 32ºF to 300ºF, will corrode at a much higher rate than if the pipe was below freezing (ice is a poor conductor) or above 300ºF where liquid water would have evaporated. A temperature range of 200ºF to 240ºF has the greatest corrosion potential as there is plenty of heat energy available, but not enough heat energy to efficiently evaporate moisture before it encounters the pipe surface. Ideally, the insulation system would be properly installed on a clean, dry pipe protected from rainfall and flooding with carefully installed and maintained jacketing.

Once the insulation gets wet, heat loss from the system will increase dramatically. Unfortunately, that also means increased surface temperatures which can cause burns to facility personnel as well as creating a great deal of inefficiency in the system. Wet insulation must be dried or removed as quickly as possible. It has been shown that the longer the pipe surface is subjected to a wetted condition, the higher the potential for corrosion. This behavior is described by one or more of the following commonly used test methods.

**Moisture Testing**

Every industrial insulation material responds to water and moisture differently. Insulation materials are typically tested for water vapor sorption, water wicking, submersion in water or entrained water in the material prior to delivery from the manufacturing facility. Tests used to measure responses to moisture are described below.

**Water Vapor Sorption (ASTM C1104)\(^2\)** – Insulation samples are weighed and placed in a humidity chamber at 120ºF and 95% relative humidity for 96 hours. The samples are weighed to determine the amount of water vapor the material has absorbed under these conditions. This test is required for fiber glass, mineral wool and aerogel blankets, each of which are allowed to contain up to a 5% weight gain.

**Water Vapor Transmission (ASTM E96)\(^3\)** – Insulation samples are cut and installed over a pan containing either a desiccant (dry cup method) or distilled water (wet cup method). The pan with the insulation and desiccant/water is weighed and placed in a chamber where a constant temperature and humidity is maintained. The pan is weighed on regular intervals to determine the rate that the pan is gaining weight (dry cup) or losing weight (wet cup). Results can vary between the two methods. However, both tests will demonstrate the difference between a vapor open and vapor retarding material. From this information a permeance or “perm” rating can be calculated. The higher the perm rating, the greater amount of moisture that can pass through a given material. Perm ratings of 10 or higher are common for industrial insulations.

It must be noted that high temperature industrial insulations are not required to have this testing performed. However, it’s important to know that most industrial insulation materials are “vapor open” which allow water vapor to pass through the insulation which aids in drying should the insulation get wet. The desiccant (dry cup) method is shown below.

---

1. NACE – General Cost of Corrosion Study. https://www.nace.org/resources/general-resources/cost-of-corrosion-study
Moisture Content (ASTM C1616) – Insulation samples are weighed, heated to 230ºF for two hours and weighed again after the samples have been allowed to cool. A common requirement limits the change in weight to no more than 1.0 kg/m² (0.20 lbs./ft²) after the 24-hour test. Materials that meet this criterion are generally considered to be "water resistant." The EN 13472 test is applied to mineral wool pipe sections (shown below). Flat mineral wool sections are tested in accordance with EN 1609, which uses the same methodology.

Submersion in Water (ASTM C1763) – Insulation samples are weighed and submerged in water for a period of time specified for the material by the ASTM standard specification. After the specified period of time has elapsed, the sample is removed from the water and weighed. The gain in the material's weight due to water must be less than the maximum amount allowed by the material's respective standard specification. This test method has three different test procedures;

- Procedure A, 48-hour submersion typically used for perlite block.
- Procedure B, 2-hour submersion typically used for aerogel blankets, cellulosic fiber insulating board and polyisocyanurate thermal insulation board.
- Procedure C, 24-hour immersion typically used for polystyrene thermal insulation board.

Dependent on the ASTM standard specification for the material, it is often required to test after exposure to elevated temperatures to provide an estimate of installed performance. Materials that specify submersion tests are typically water-resistant gaining less than 20% water, by weight, if the product has not been heat aged. Heat aging affects the water repellency of the material. For examples, heat aged perlite can have up to 50% moisture content after a 48-hour submersion.

Moisture Content (ASTM C1616) – Insulation samples are weighed, heated to 230ºF for two hours and weighed again after the samples have been allowed to cool. This test is required for perlite and calcium silicate pipe and block products which can have "as provided" moisture contents as high as 10% and 20% respectively.

Corrosion Testing

We know that corrosion typically occurs when water is introduced to the insulation system. The corrosive element and the pipe surface seemingly wait for water to bring these two things together. Before this event happens, the corrosion potential of the insulation also needs to be known. Corrosion testing provides some guidance in comparing insulation materials. Given that distilled or deionized water is used for this testing, actual results in the field can vary dramatically from lab results since most ambient water contains some level of chlorides.

ASTM C665 13.8 – Five steel coupons are sandwiched between sterile cotton and five steel coupons are sandwiched between the insulation material in question. The ten samples are placed in a chamber conditioned to 120ºF and 95% relative humidity for 96 hours. After 96 hours, all samples are removed from the chamber and the insulation and cotton are separated from their respective steel coupons. The coupons are then judged to determine if the coupons sandwiched between the insulation are conclusively more corroded than the coupons sandwiched between the sterile cotton.

This test is often used within insulation specifications. Due to the subjective nature of this test, other tests have been developed that provide quantitative results for easier interpretation of results. Aluminum and copper coupons can also be used with this test method. 

ASTM C665

1. Steel coupons are cleaned and sandwiched between sterile cotton (control) and insulation samples.
2. Samples are placed in a humidity cabinet for 96 hours.
3. Samples are removed from the cabinet and compared to each other. The coupons with the insulation sample must not have more corrosion than the coupons with the sterile cotton sample.

4. BS EN 13472:2012 "Determination of short term water absorption by partial immersion of preformed pipe insulation."
5. BS EN 1609:2013 "Determination of short term water absorption by partial immersion."
**ASTM C1617** – Twelve samples are prepared that include a plain steel coupon that has been weighed before attaching a 1” PVC pipe to the coupon with silicone sealant. Four different mixtures are created that include the insulation sample, that has been ground up in deionized water and filtered to remove the solids. Reference or control solutions include a deionized (DI) water sample, a 1 ppm chloride solution sample, a 5 ppm chloride solution sample and a 10 ppm chloride solution. Each solution will be applied to three plates. The coupon assemblies are placed on a hot plate that will maintain a constant temperature of 230ºF during the 96 hour test. The solutions are then dripped onto the coupons at a rate of 250 ml per day for four days creating thousands of wet-dry-wet cycles in a short period of time. At the end of the test, the coupons are cleaned and reweighed. Using the change in weight of the steel coupon during the test, a Mass Loss Corrosion Rate (MLCR) in mils of thickness is calculated. The MLCR of the sample is then compared to the DI, 1 ppm, 5 ppm and 10 ppm chloride solution MLCR results. The MLCR of the tested material must perform equal to or better (lower change in weight) than the MLCR requirement stated in the ASTM standard specification for the material. In the case of mineral wool, the corrosion rate of the insulation would have to be less than the 5 ppm chloride reference sample.

**ASTM C871** – Insulation samples are ground up and boiled in distilled or de-ionized water to create a “leachate”, similar to what was done in ASTM C1617. The leachate is then evaluated to determine the concentrations of chlorides and fluorides, which accelerate corrosion. The concentrations of sodium and silicates are also evaluated as these compounds have been found to inhibit stress corrosion cracking caused by chlorides and fluorides.

**ASTM C692** – An insulation pipe section is placed over a stainless steel coupon formed to fit around a heated pipe that maintains a temperature of 212ºF. Distilled or deionized water is passed through the insulation sample at a rate of 250 ml per day for 28 days. At the end of 28 days, the stainless steel sample is evaluated for signs of cracking. If cracks are not observed, the insulation material passes the test.

**ASTM C1617**
1. Insulation and DI water is ground together.
2. The solid is separated from the solution.
3. Steel coupons are cleaned and weighed.
4. The insulation solution is dripped onto the steel coupon that has been heated to approx. 230ºF for 96 hours. Additional control solutions are also prepared and dripped onto other steel coupons:
   - DI water
   - 1 ppm chloride solution
   - 5 ppm chloride solution
   - 10 ppm chloride solution
5. After 96 hours, the steel coupons are cleaned and reweighed.
6. The change in weight is used to calculate the Mass Loss Corrosion Rate (MLCR).
7. Results are reported relative to the control samples i.e. “less than DI water” or “less than 10 ppm chloride solution”.

**ASTM C871**
1. Stainless steel coupon is formed to go around a pipe section.
2. Insulation is mounted over the coupon. Distilled/DI water is dripped through the insulation until it reaches the pipe.
3. The pipe is heated 212ºF (boiling).
4. The test is run for 28 days.
5. After 28 days, the sample is checked for signs of cracking.
6. Insulation materials pass if cracks are not observed.

Used for stainless steel only.
ASTM C795 – The results from C871 and C692 are used to determine compliance to this standard specification. The chloride and fluoride concentrations obtained from C871 (in ppm) are added together and plotted on the vertical axis of a logarithmic plot. Likewise, the sodium and silicate concentrations from C871 (also in ppm) are added together and plotted on the horizontal axis of a logarithmic plot. The plotted point must be within the “Acceptable Analysis” region of the plot to comply with C795. The sample must also pass the ASTM C692 test for External Stress Corrosion Cracking (ESCC) with no cracking of the stainless steel coupon to meet this requirement.

Discussion
The best way to deal with CUI is to prevent water from entering the insulation system in the first place. The use of water repellent additives with insulation materials prevents water from entering the insulation system should water find its way past the jacketing. Moisture is simply retained between the jacketing and the insulation until it can find its way out by either draining as a liquid or diffusing through gaps in the jacketing as water vapor. It should be noted that water can bypass the insulation if there are any gaps or penetrations in the installation. Again, proper installation of the insulation and jacketing is crucial to preventing CUI.

Corrosion inhibitors have been used with industrial insulation systems and promise superior corrosion resistance by neutralizing potentially corrosive elements, typically chlorides, before they reach the surface of the pipe surface. It must be noted that while these corrosion inhibitors typically work well for their intended application, the insulation must be in contact with the surface of the pipe to be effective. Surrounding areas such as the underside of the pipe in the annular space between the insulation and the pipe would be subjected to a hot, humid conditions that are ideal for corrosion. This situation is particularly worrisome if the water intrusion was due to flooding. Chloride-enriched flood water next to a hot pipe is a recipe for pipe failure.

In a perfect world, the insulation would be impervious to water and able to neutralize all corrosive elements. For most hydrophobic or water-resistant insulations, water repellency is compromised when the material reaches approximately 600°F. This generally only occurs on pipe insulation within the first inch of thickness next to the pipe even at process temperatures of 1200°F. The remaining thickness of insulation material will retain its water repellency.

Conclusion
Owens Corning’s Thermafiber® Pro Section WR mineral wool pipe insulation, with its open fibrous structure and low density, doesn’t retain as much water as other industrial insulation types. This structure allows Thermafiber® Pro Section WR mineral wool pipe insulation to dry quickly without trapping water or impeding water vapor transmission as moisture exits the system. Mineral based insulations such as calcium silicate and expanded perlite are approximately 85% denser than an equivalent performing mineral wool pipe product. Calcium silicate and expanded perlite can “hold” more moisture due to their heavier weight and physical characteristics, and require more energy to evaporate the additional moisture in the event the insulation becomes saturated. This means longer drying times and increased corrosion potential. The increased weight of wet calcium silicate on pipe hangers could also cause problems.

Given Owens Corning’s Thermafiber® Pro Section WR mineral wool pipe insulation’s lower density and water repellency up to 482°F (250°C), water residence time is dramatically reduced. This is due to a lower amount of water that can be absorbed when compared with untreated mineral wool products or materials that are not inherently water resistant such as calcium silicate.

The solution in designing the insulation system is to minimize, if not prevent, the potential for corrosion. This can be as simple as selecting the right insulation, ensuring proper installation and maintaining the insulation and jacketing system. Below are recommendations to provide guidance.

• The goal is to reduce the potential amount of overall moisture in the system in the event of water intrusion. Reducing the amount of moisture reduces drying time if water is introduced to the system.
• Select an insulation appropriate for the application that is water resistant, such as Owens Corning’s Thermafiber® Pro Section WR mineral wool pipe insulation.
• Provide the correct thickness of insulation to the job site in a clean and dry condition.
• Ensure that all circumferential and longitudinal joints are closed. Longitudinal joints between sections should be offset 180 degrees.
• Cut insulation to fit snugly against any penetrations.
• Ensure proper jacketing thickness is specified and installed properly. Joints should be lapped in such that water sheds away from the jacketing. Overlaps should be at least 2” (51mm).

12 ASTM C795 “Standard Specification for Thermal Insulation for Use in Contact with Austenitic Stainless Steel”
• On horizontal pipe runs, the downward facing longitudinal edge of the jacketing should be in either the 4 or 8'o'clock position and lapped over the top of the bottom edge to "shingle" the water away from the pipe.
• The longitudinal and circumferential jacketing joints should be sealed with a suitable sealant.
• All penetrations must be sealed to prevent moisture ingress.
• In high traffic areas, use support rings or thicker jacketing to prevent potential damage to the jacketing.
• Once the insulation has been installed, periodically check the insulation system for signs of physical damage such as dented jacketing, missing banding and water ingress.

Installation details:

ENSURE PROPER OVERLAP OF JACKETING/LAGGING AND SEAL CIRCUMFERENTIAL AND LONGITUDINAL JOINTS.