Causes and Prevention of Corrosion on the Interior Surface of Metal Jacketing Used on Mechanical Insulation

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Summary:
Mechanical insulation systems are used on cold and hot pipe, tanks, ducts, vessels and equipment to conserve energy, prevent surface condensation, prevent contact burns, and more. In most outdoor applications and some indoor locations, these systems use an outer protective metal jacketing to provide UV resistance, damage resistance, and water shedding. Regardless of metal type, this jacketing is susceptible to galvanic and pitting/crevice type corrosion on the interior surface caused by the intrusion of water into the insulation system. The best way to prevent this corrosion is to factory heat laminate a 76 µm (3 mil) multilayer polysurlyn moisture barrier to the interior surface of the metal jacketing.

Background:
Insulation is used on the exterior surface of pipe, tanks, ducts, vessels and equipment for the same reason insulation is used on building envelopes - to reduce the flow of heat. In this application, the insulation is part of a complex construction generically called a mechanical insulation system which can include one or more layers of insulation, adhesive at the insulation joints, vapor retarder, and metal jacketing. These systems are often more complicated than building envelope insulation because of their complex geometry, the unidirectional heat/moisture flow, the extreme temperatures of the mechanical equipment being insulated, and the often outdoor exposed location of the systems. Table 1 shows some common examples of outdoor mechanical insulation systems, their operating temperatures, and a brief description of the insulation system.

Mechanical insulation systems for hot applications are applied to pipe/equipment that can be hotter than 649°C (>1200°F) and the main purposes of the insulation system are to improve energy efficiency, prevent contact burns, and maintain process control. Secondary effects of the insulation system can include improved fire resistance and sound deadening. Examples of the applications for hot mechanical insulation systems are mundane hot service water in a commercial building, power plants, oil/gas refining and cracking, petrochemical manufacture, and food production.

Mechanical insulation systems for cold applications are applied to pipe/equipment that ranges from just below ambient temperature to near absolute zero -273°C. The main purposes of the insulation system are to improve energy efficiency, minimize condensation on the system surface, prevent contact burns, and maintain process control. Examples of the applications for cold mechanical
insulation systems are food/beverage refrigeration, commercial building chilled water air conditioning, liquid natural gas handling and shipping, and petrochemical manufacture.

Table 1 – Common mechanical insulation systems

<table>
<thead>
<tr>
<th>Insulation System Type</th>
<th>Pipe/Equipment Contents</th>
<th>Operating Temp. °C (°F)</th>
<th>Outdoor Mechanical Insulation System Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power plant</td>
<td>Exhaust gas</td>
<td>&gt;649°C (&gt;1200°F)</td>
<td>Refractory fiber / stainless steel jacketing</td>
</tr>
<tr>
<td>High pressure steam</td>
<td>Steam</td>
<td>&gt;260°C (&gt;500°F)</td>
<td>Mineral wool / aluminum jacketing</td>
</tr>
<tr>
<td>Hot oil/gas and petrochemical</td>
<td>Various organics</td>
<td>38 to 260°C (100 to 500°F)</td>
<td>Mineral wool / aluminum or stainless steel jacketing</td>
</tr>
<tr>
<td>Cold oil/gas and petrochemical</td>
<td>Various organics</td>
<td>-101 to 16°C (-150 to 60°F)</td>
<td>PIR insulation / vapor retarder / aluminum jacketing</td>
</tr>
<tr>
<td>Commercial bldg. air conditioning</td>
<td>Chilled water</td>
<td>4°C (40°F)</td>
<td>Phenolic insulation / vapor retarder / aluminum jacketing</td>
</tr>
<tr>
<td>Food/Beverage Refrigeration</td>
<td>Ammonia, CO2, HCFC</td>
<td>-51 to 4°C (-60 to 40°F)</td>
<td>Multi-layer XPS insulation / vapor retarder / aluminum jacketing</td>
</tr>
<tr>
<td>Liquid natural gas (LNG)</td>
<td>Liquid methane</td>
<td>-165°C (-265°F)</td>
<td>Three layer PIR insulation / two vapor retarders / aluminum jacketing</td>
</tr>
</tbody>
</table>

Due to the complex nature of mechanical insulation systems, they are typically designed by engineers hired directly by the facility owner or architect, or by a subcontracted engineering design firm. Specifications for mechanical insulation can range from very simple short documents to more than 100 pages depending on the complexity of the job and insulation system.

**Metal Jacketing and Interior Surface Corrosion:**

Entire volumes could and have been written on the subject of mechanical insulation systems but this document will focus on the metal jacketing and, more specifically, on specific types of corrosion that metal jacketing on mechanical insulation systems is prone to.

Very few insulation materials can be left exposed in outdoor applications so metal jacketing is widely used to protect the insulation system from damage due to UV exposure, physical abuse, and environmental water. Many types of metal have been used as jacketing including aluminum, stainless steel, aluzinc, aluminized steel, and even galvanized steel. Of these, the most commonly used in N. America are aluminum and stainless steel and the use of both of these materials is growing outside of N. America also. Outside of N. America, aluzinc and aluminized steel are very popular. All metal types have various benefits and disadvantages but all have two key weaknesses germane to this discussion. They all have joints which are impossible to perfectly seal against water penetration and all can exhibit the type of interior surface corrosion that is the focus of this paper.

Water intrusion into the insulation system through the joints in the metal jacketing is inevitable because these joints cannot be made water-tight using adhesives/sealants. In addition, damage to metal jacketing is common due to factors such as hail, wind, being walked on, and leaning of ladders against.
The source of the water which enters the insulation system from the ambient surroundings includes rain, condensation, dew, mist, fog, snow, cooling tower spray, and even ocean spray.

When water does enter the insulation system, its specific location will depend on various factors including whether a vapor retarder is present on the surface of the insulation and the integrity of this vapor retarder. Hot applications typically do not have a vapor retarder present and in this case, any water that enters can migrate throughout the insulation system subject to the influence of gravity, temperature, and other factors. Cold applications usually have a vapor retarder which should be fully intact on the outer surface of the insulation. Any water that penetrates through the joints in the metal jacketing will collect in the small space between the vapor retarder and the metal jacketing. This is shown pictorially in Figure 1.

Figure 1 – Location of water in hot and cold insulation systems

When water penetrates through the joints in the metal jacketing it can cause corrosion of the interior surface of the jacketing and, in some cases, of the pipe/equipment. This type of corrosion is not the classic corrosion under insulation (CUI) which refers to corrosion of the pipe/equipment and is caused by water in direct contact with the pipe/equipment. This is also not corrosion of the edges of the metal jacketing which can occur with the coated steel type jacketing (aluzinc, galvanized, and aluminized steel). Because this type of corrosion occurs on the interior surface of the jacketing, it is very hard to detect until it becomes so egregious that the corrosion penetrates completely through the metal leaving visible holes in the jacketing. Often, this type of corrosion is assumed to actually be corrosion that begins on the exterior of the jacket because it is not observed until a hole has formed in the jacket at which point the two loci of corrosion (interior and exterior) are difficult to distinguish.

This interior corrosion can occur starting almost immediately after installation and reach the point of forming holes in the jacketing in as quickly as 6 months. This corrosion cannot be repaired either at its beginning stages or at the point where it has formed holes in the jacket. All that can be done to fix this problem is to replace the metal jacketing; a very expensive endeavor. As with most corrosion, it is far better to protect the metal initially so as to prevent the corrosion from occurring than to attempt to fix the problem after it has occurred. Figure 2 shows several pictures of interior jacket corrosion that has progressed to form holes through the jacketing.
Figure 2 – Holes resulting from interior jacket corrosion

Types of Corrosion Causing Interior Surface Jacket Corrosion:

This paper will not address the detailed chemistry of corrosion but will discuss briefly the two types that can lead to interior surface jacket corrosion – galvanic and crevice/pitting.

Galvanic or dissimilar metal corrosion occurs when two different metals are coupled in the presence of an electrolyte. V. Mitchell Liss describes the source of galvanic corrosion in mechanical insulation systems as, “Galvanic corrosion generally results from wet insulation with an electrolyte or salt present that allows a current flow between dissimilar metals (i.e., the insulated metal surface and the outer jacket or accessories).”

Galvanic corrosion can occur with all types of metal jacket and is most prevalent in hot applications where wet insulation can touch both the jacket and the pipe/equipment forming a bridge between the dissimilar metals. When this occurs, the more active metal corrodes. This is usually the jacket but can be the pipe/equipment when stainless steel jacketing is used with carbon steel pipe/equipment. The presence of water in the insulation system is necessary for this type of corrosion since it is both the electrolyte and an excellent source for the ions that give the water its electrical conductivity. A convenient way to describe galvanic corrosion is that it occurs when two dissimilar metals are coupled in a single environment.

Crevice and pitting corrosion are very similar in both their chemistry and result. Since it is unclear if one or both of these occurs in interior jacket corrosion, they will be considered together as the other type of corrosion. Crevice/pitting corrosion is a localized form of corrosion associated with a stagnant solution in contact with metal. This corrosion type can occur when a small droplet of water is trapped between the interior surface of the metal jacketing and either the insulation or a vapor retarder on the outside surface of the insulation. This thin space between the jacket and the underlying surface acts like a crevice & moisture trapped in this “crevice” can lead to crevice/pitting corrosion, especially when chlorides are present in the water as they are in most environmental sources of water. To function as a corrosion site, this “crevice” must be large enough to permit entry of water but small enough to keep the water stagnant. This can readily occur in the thin gap between metal jacket and vapor retarder. Crevice/pitting corrosion can occur with aluminum, coated steel, and even stainless steel type jacketing. All stainless steels are susceptible to crevice corrosion. The commonly used type S304 stainless is susceptible to crevice/pitting in the presence of salty water above about 10°C (50°F) and the less commonly used type S316 stainless is more resistant but can be attacked if the temperature increases even slightly above 10°C (50°F). Pitting and crevice corrosion together account for perhaps 25% of all corrosion failures in stainless steel. Most mechanical insulation systems are designed such that the jacket temperature is fairly close to the ambient temperature and NOT to the
pipe/equipment temperature so it is very easy to get above 10°C (50°F). A convenient way to describe crevice/pitting corrosion is that it occurs when one metal type is in the presence of two connected micro-environments.

As this section makes clear, corrosion science offers an explanation for why corrosion on the interior surface of metal jacketing can occur. But where has this type of corrosion been observed? The next sections will describe the lab testing where this corrosion can be seen and the real world installations where corrosion on the interior surface of metal jacketing has led to expensive repairs.

Lab Testing of Resistance to Interior Surface Jacket Corrosion:

Lab corrosion tests were conducted to examine the potential for galvanic or pitting/crevice corrosion of various metal jacketing and to demonstrate how effective polysurlyn moisture barrier (PSMB) was at preventing this type of corrosion.

For the first of this testing, a mock-up of a common mechanical insulation system was constructed. Standard carbon steel pipe was covered with mineral wool insulation which was then covered with various types of metal jacketing both with and without PSMB lining. When PSMB lined metal jacketing was used, an X was scribed through the PSMB to mimic damage that might occur during handling and installation. The fibrous insulation used in this test was a way to keep the pipe and jacket separated while also allowing the added salt water to form a bridge between these two metals due to the open-cell/fibrous nature of the mineral wool. The mineral wool insulation was wetted with salty water and an induced electrical potential was applied between the pipe and jacket to accelerate galvanic corrosion. Each test lasted only 75 minutes. At the end of this time the underside of the metal jacketing was examined for evidence of corrosion.

Four different types of metal jacketing were examined in this test, 3105 aluminum alloy, aluzinc coated steel, galvanized steel, and aluminized steel. For all four bare metal types, there was significant corrosion visible on the surface in contact with the insulation. In the tests where a PSMB was applied to the metal jacketing, there was no corrosion present. Figure 3 shows pictures of the jacketing after this testing was complete.

In a second lab test, a similar experiment was conducted but the jacketing was stainless steel and the pipe was carbon steel. In this case the corrosion would be expected to occur on the pipe. Four 75 minute long voltage applications were made and the pipe examined after these exposures. When both type S304 and S316 bare jacketing was used, the pipe exhibited significant corrosion. When both types of stainless jacketing were lined with PSMB, no pipe corrosion occurred. Figure 4 shows the pipes after this testing was completed.

In addition to the visual observation of corrosion, the mass loss due to corrosion for each pipe was determined. It was found that when the stainless steel jacketing had a PSMB there was no mass lost from the underlying pipe due to corrosion. When bare stainless steel jacketing was used, the mass lost from the pipe was 3.5% for type S304 stainless jacket and 2.5% for type S316 stainless jacket. Note that this large amount of mass loss occurred after only four 75 minute exposures to the corrosion conditions. Figure 5 shows this result graphically.
Figure 3 – Corrosion results from lab testing of various types of metal jacketing

Bare 3105 Aluminum  Bare Aluzinc  Bare Galvanized  Bare Aluminized steel

PSMB with scribed “X” on 3105 Aluminum  PSMB with scribed “X” on Aluzinc

All bare metal jacketing showed rapid corrosion in even these 75 minute tests

Use of PSMB eliminated all corrosion in these tests

Figure 4 – Pipe corrosion results from lab testing of various types of stainless steel jacketing

Carbon steel pipe under bare S304 jacket  Pipe Under Bare S316 Jacket

Carbon steel pipe under PSMB lined S304 jacket  Pipe Under PSMB Lined S316 Jacket

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In this case, the corrosion science previously discussed and the lab testing are in agreement. Science shows why the corrosion can occur and why an effective moisture barrier on the interior surface of the metal jacketing should prevent this type of corrosion. The lab results are in complete agreement with the theory. Bare metal jacketing leads to interior surface jacket (or pipe) corrosion and the use of PSMB prevents this corrosion from occurring. The use of PSMB on metal jacketing protects all types of metal jacketing from this corrosion and protects the pipe under the insulation from this corrosion when the jacket is stainless steel.

While this lab testing was a simulation, the difference between these accelerated lab tests and actual field experience is only the time required for failure.

**Real-World Results:**

In this section, several real-world examples will be provided showing the results of using an inadequate moisture barrier and how an effective moisture barrier can prevent interior surface jacket corrosion. When examining problems or failures in real-world installations it is usually difficult to obtain high quality information. Everyone involved in these type problems including facility owners, design engineers, and installation contractors are reluctant to publish or even allow discussion of their problems. In some cases there are even legal agreements prohibiting the parties from discussing the issues. In addition, when there is a real-world problem or failure, the facility owner wants it corrected as quickly as possible to minimize shutdown time. These factors along with the many variables involved in a real-world situation make it difficult to be scientific and it is hard to quantify these problems or carefully examine the solutions. Even with all of these constraints, examples still exist of facilities where interior surface metal jacket corrosion has occurred and enough information is known to make discussion of the failure a useful learning opportunity.
Table 2 below describes six real-world cases where interior surface metal jacket corrosion was encountered. For obvious reasons, no specific company or facility names are used. In all of these real-world examples the metal jacketing was aluminum with a polykraft moisture barrier.

Table 2 – Real-world examples of interior surface metal jacketing corrosion

<table>
<thead>
<tr>
<th>Facility Description</th>
<th>Application Type</th>
<th>Insulation System</th>
<th>Climate Type</th>
<th>Corrosion Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food/beverage plant in PA, USA</td>
<td>Ammonia refrigeration, continuous use</td>
<td>PIR with ASJ vapor retarder</td>
<td>Cold</td>
<td>Significant interior surface jacket corrosion six years after installation. Jacketing was replaced</td>
</tr>
<tr>
<td>Four power plants in NE, USA</td>
<td>Hot pipe, intermittent use</td>
<td>Mineral wool</td>
<td>Cold</td>
<td>Significant interior surface jacket corrosion</td>
</tr>
<tr>
<td>Three asphalt plants in USA</td>
<td>Hot pipe, intermittent use</td>
<td>Glass fiber with ASJ vapor retarder</td>
<td>Cold</td>
<td>Significant interior surface jacket corrosion</td>
</tr>
<tr>
<td>Six cold storage warehouses</td>
<td>Rooftop ammonia refrigeration, continuous use</td>
<td>XPS Pipe Billet with ASJ vapor retarder</td>
<td>Hot &amp; cold</td>
<td>Water present between ASJ and jacket. Significant interior surface jacket corrosion. Jacketing was replaced</td>
</tr>
<tr>
<td>Heavy equipment factory</td>
<td>Chilled water, continuous use</td>
<td>Cell glass with ASJ vapor retarder</td>
<td>Hot</td>
<td>Significant interior surface jacket corrosion</td>
</tr>
<tr>
<td>Hospital</td>
<td>Chilled water, summer use only</td>
<td>Glass fiber with ASJ vapor retarder</td>
<td>Cold</td>
<td>Significant interior surface jacket corrosion</td>
</tr>
</tbody>
</table>

Figure 6 shows pictures of the poor condition of the polykraft moisture barrier and the interior surface corrosion holes in the metal jacketing from the first real-world example in Table 2.

In addition to these examples of corrosion actually occurring when polykraft moisture barrier is used, there is an important related observation. ITW Insulation Systems is one of the largest global providers of metal jacketing for mechanical insulation systems and the employer of this author. They sell primarily jacketing with PSMB and have never had a claim or any knowledge of a case of interior surface corrosion occurring when a PSMB was used on the metal jacketing.

It has been shown that corrosion science, lab test results, and now real-world field experience are all in agreement. Interior surface jacket corrosion is an equal opportunity thief. It can steal longevity from insulation systems in all industries, all applications, using all insulation types, with all metal jacketing types, and in all climates. The best way to prevent the occurrence of this type of corrosion is the use of an effective moisture barrier like PSMB on the interior surface of the metal jacketing.

Moisture Barriers:

There are three general types of moisture barriers used on metal jacketing in mechanical insulation systems – paint, polykraft, and polysurlyn. Painted moisture barrier is a thin (~18 µm, 0.7 mil) layer of lightly pigmented paint that is typically applied in the mill that produces the metal coils. This type of
Figure 6 – Pictures of real-world interior surface metal jacket corrosion

moisture barrier is common on pre-formed two-piece elbows where it is probably acceptable due to the ultrapure corrosion resistant alloy of aluminum used on these elbows. Polykraft is a layer of kraft paper laminated to a single thin layer of polyethylene film. This lamination is performed by a metal jacketing company. Polykraft is outdated and ineffective technology. Polysurlyn moisture barrier (PSMB) is a thick three layer film that is applied by a jacketing company and represents the current state of the art for moisture barriers.

The real-world examples described above strongly indicate that polykraft is ineffective and PSMB is quite effective at preventing this corrosion but why is this? To answer this, the properties of the various moisture barriers must be considered in light of the main purpose of the moisture barrier which is to keep water from contacting the underside of metal jacketing to reduce corrosion potential.

With this purpose in mind, the key properties of a moisture barrier are:

- Pinholes – Each pinhole is a place where corrosion can start
  - Fewer is better and zero pinholes is most desirable
- Water resistance – Keep the corrosive water from touching the interior metal surface
  - Low water absorption and low water vapor transmission rate are desirable
- Toughness/durability – Damaged or decayed moisture barrier from the inevitable rough handling and installation is a locus for possible corrosion
  - Strong, tough, scratch resistant, and durable film is desirable
- Flammability – Lower flammability is preferred

Table 3 shows the performance of each moisture barrier type in these key properties.
Table 3 – Properties of moisture barriers

<table>
<thead>
<tr>
<th>Property</th>
<th>Paint</th>
<th>Polykraft</th>
<th>Polysurlyn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Barrier Description</td>
<td>1 layer at ~18 μm (0.7 mils)</td>
<td>1 layer of 38 μm (1.5 mil)</td>
<td>3 layer polymer film with total thickness of 76 μm (3 mils)</td>
</tr>
<tr>
<td>Pinholes per 4.0 m² (50 ft²) via ASTM C1729 Method</td>
<td>&gt;19</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Water Resistance WVTR (g/100 in²-day)</td>
<td>Unknown</td>
<td>Poor at about 1.0</td>
<td>Excellent &lt;0.05</td>
</tr>
<tr>
<td>Toughness</td>
<td>Easily scratched</td>
<td>Paper easily damaged</td>
<td>Strong and scratch resistant</td>
</tr>
</tbody>
</table>
| Flammability                  | Good                           | Unknown but exposed paper surface has Autoignition temp of ~232°C (450°F) | Tested on aluminum using ASTM E84 yielding flame/smoke of 0 / 5  
|                               |                                |                               | Autoignition temp for polysurlyn is >316°C (600°F) |

As corrosion science, lab testing, real-world examples, and now moisture barrier properties demonstrate, polysurlyn moisture barrier is the most effective way to prevent interior surface corrosion of metal insulation jacketing because it:
- Has proven performance
- Has no pinholes
- Is a multilayer film
- Has very low water vapor transmission rate
- Has very low water absorption
- Is tough, scratch resistant, and durable
- Has very low flammability
- Has excellent adhesion to metal substrates
- Is available on all metal types
- Is available from many metal jacketing manufacturers

**Contractor and Facility Owner Recommended Actions:**

Insulation contractors should minimize damage to the moisture barrier during cutting, field fabrication, and installation. They should educate workers on moisture barriers and their importance. They should buy metal jacketing only with PSMB. For aluminum jacketing, the easiest way to assure it has a PSMB is to use the new ASTM standard for this type of jacketing and specify that it comply with ASTM C1729, Type I, Grade 1 or 2, Class A. Lastly, contractors should recommend the use of PSMB lined metal jacketing to specifiers, engineers, and owners who are unaware of its importance.

Owners and engineers should specify metal jacketing only with PSMB. For aluminum jacketing, the easiest way to assure it has a PSMB is to use the new ASTM standard for this type of jacketing and specify that it comply with ASTM C1729, Type I, Grade 1 or 2, Class A. Lastly, owners and
engineers should ensure that contractors know about PSMB and know to minimize damage to it during handling and installation.

**Conclusions:**

Interior surface corrosion of metal jacketing on mechanical insulation is a major potential problem with all metal types. All metal insulation jacketing should have 76 µm (3 mil) thick polysurlyn moisture barrier (PSMB) factory heat laminated on the inside surface to protect against jacket corrosion for aluminum and aluminum coated steel jacket and to protect against pipe corrosion when stainless steel jacket is used. Use of PSMB is cheap insurance to prevent the very costly alternative of jacket corrosion.

Contractors and Owners should use/specify PSMB on the inside surface of all metal jacketing and minimize damage to the moisture barrier during handling and installation.

**References:**

1. V. Mitchell Liss, corrosion engineering consultant, Preventing Corrosion Under Insulation, Bulletin of the National Board of Boiler and Pressure Vessel Inspectors, January, 1988

2. www.corrosionist.com

3. www.corrosion-doctors.org