

WATER INFILTRATION IN PIPE INSULATION

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“WATER, WATER, EVERYWHERE.....”

Refrigeration systems operate to remove heat from isolated areas. Insulation is used to reduce the absorption of heat from any environment except the target. Preserving the insulation is a requirement for long-term system cost-efficiency. External damage due to rough treatment may be obvious to the eye and is generally preventable. A less obvious, but certainly important and widespread problem is that of water infiltration.

THE MECHANISMS OF WATER INTRUSION AND MOVEMENT

There are a number of methods whereby liquid or evaporated water moves into and throughout the insulation of a refrigeration system. Included in these methods are **Vapor Drive**, **Vapor Exchange** and **Capillary Action**.

Vapor Drive is the movement of water molecules through the external vapor retarder (and the insulation itself) due to the partial vapor pressure difference between the air on one side of the material and that of the other. During this process, the barrier material acts like a permeable membrane, limiting (but definitely not preventing) the transport of vapor. If the exterior air has a higher humidity, it has a

greater number of energetic water molecules bouncing about via Brownian movement than does the interior. The barrier contains a statistically significant number of holes through which molecular water may pass. There are more chances for water molecules to find a hole and migrate through on the higher humidity side, so the net water movement is from the more humid side to the less. The mass of infiltrating water can be calculated using a simple formula multiplying the rated permeability of the barrier material by the barrier area, the time and the difference in partial vapor pressures of water between the interior and exterior air masses.

Vapor Exchange occurs in the real world (where no vapor barrier is perfect) when moist air mixes directly with the relatively dry air inside the insulation volume through cracks and seams in the vapor retarder.

Capillary Action is the transport method whereby liquid moves throughout the insulation. Water, which infiltrates as vapor, soon encounters the temperature in which it tends to condense. Surface tension enables water to move itself through small tubes or fissures, even in defiance of gravity. Capillary Action is also called “wicking,” and is the same process that moves liquid fuel to the point where it is evaporated and burned in a lamp.



External icing due to water infiltration.

THE DAMAGES

The water which intrudes into insulation has important destructive **Thermal** and **Non-thermal** effects on the system.

Thermal losses are due to reduced insulation efficiency (when it contains water or ice) and when water or vapor in contact with the system undergoes a phase change. Liquid water conducts heat approximately 20 to 50 times better than the isolated chambers of air which constitute the bulk of industrial insulation materials. Soaked insulation is therefore severely

compromised. Another direct thermal loss is that of the latent heats of condensation and fusion of water. For every pound of water condensing in or on the insulation, 973 BTUs are removed from it. If that water freezes, a further 144 BTUs per pound are removed.

Non-thermal effects include the actual destruction of the insulation, the growth of molds and bacteria and the corrosion of the system piping. In non-freezing applications, water in sufficient quantities can cause an addi-

tional structural load on the insulation whereby it physically tears away from the pipe. In systems where intruded water freezes, the expansion which accompanies that phase change also tears the insulation material and crushes the air cells. Finally, wherever liquid water comes in contact with metal alloys, it facilitates corrosion. Particularly in refrigeration hot gas defrost lines, elevated-temperature-enhanced corrosion has been linked to catastrophic leaks and system failures.

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SOLUTIONS

Logically, the refrigeration user has two courses of action: either prevent the intrusion of water in the first place or, where it has occurred, remove it.

Complete prevention of vapor drive-related water intrusion is a practical impossibility. In a system carrying -25°F Ammonia through 6 in. pipe with 4 inches of insulation and a vapor retarder rated at 0.02 perm, for instance, nearly 5 pounds of water per 100 feet of pipe intrude annually (at 75°F and 75% humidity). Vapor retarders with permeation ratings as low as 0.0001 perm are available and may reduce the threat of water intrusion via vapor drive. An aggressive schedule of inspection and repair is required, however, to prevent direct vapor exchange through damaged areas. Such maintenance

regimens have been rare, in our experience. Water will also continue to infiltrate even the best vapor retarders through the inevitable seams and joints.

For systems which have been in place for several years and suffer from water infiltration already, a more active approach must be applied.

The most widely practiced (and expensive) method is to simply periodically (often every 5 to 10 years) replace the insulation and vapor retarder throughout the portions of the system that experience failure. Waiting for failure, however, is less palatable, since it is accompanied by unexpected capital expenditure, unplanned system down-time and negative environmental impact.

For systems which operate at above freezing tempera-

tures, a non-mechanical option may be available. Moisture which has condensed upon cold piping may be removed by capillary action to another site to drip away or be evaporated. Such “wicking” water-removal systems are extremely simple in conception, but may be limited by the external conditions. The end of the “wick” must be exposed to an environment which will allow the moisture to evaporate or drip away, but the wick area must be small enough so that the vapor drive which occurs during system operation doesn’t move more vapor into the system than is removed via capillary action. Systems which regularly cycle from cold to ambient temperatures would seem to be particularly suited to this method.

In applications with be-

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SOLUTIONS CONTINUED

low-freezing operating temperatures, the intruded water may be removed by evaporation (when liquid) or sublimation (when frozen) into an injected dry gas, which is then vented from the insulation. Buried telephone cables have been dried for years by the periodic injection of dry Nitrogen gas, for instance. A less-expensive alternative utilizes extremely dry air that is continuously distributed throughout the insulation volume by perforated tube.

Dry air injection has several advantages over other

alternatives. First, and perhaps most important, it may be installed into operating refrigeration systems without requiring a shutdown and at a fraction of the cost of insulation replacement. As the dry air is circulated, the insulation, when relieved of intruded water, returns in large part to its initial efficacy. According to the 3E Plus 3.0 Insulation Effectiveness Calculator (available at www.naima.org, the website of the North American Insulation Manufacturers Association), the outermost half inch

of insulation provides almost 90% of its R-value. Since dry air injection recovers the near-surface insulation first, the bulk of insulation efficiency may be restored within a matter of months. The slight over-pressure applied to the air volume within the insulation has the added benefit of preventing vapor exchange through cracks and seams, improving the performance of even the most impermeable vapor barriers.



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CONCLUSION

Water infiltration is inescapable as long as the environment is humid enough for comfortable living. Due to the operating parameters of refrigeration systems, infiltrated water tends to remain and move throughout the insulation, causing damage and reducing thermal efficiency. New vapor retarders, coupled with an aggressive inspection and repair program, promise to reduce intrusion, but can do nothing for seam- or crack-related vapor exchange or existing systems (with older, damaged vapor retarders) that have water infiltration already. The most cost-effective solution for the broad range of existing refrigeration systems and operating environments is dry air injection, installed prior to initial start-up or retroactively.



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