TECHNICAL BULLETIN 0720

Cold Temperature Pipe Insulation: *Mission Critical*

INTRODUCTION

Dyplast's® Technical Bulletins are intended to provide in-depth and objective information and comparisons of various insulants, including polyisocyanurate versus polyurethane, polystyrene, cellular glass, fiberglass, elastomeric, and others. Our Qwik Guides typically offer abbreviated (one-page) technical perspectives, sometimes referencing Technical Bulletins.

As always, if any reader credibly argues that Dyplast has materially *misstated* or *misinterpreted* facts, we will revise this and related documents!

BACKGROUND

The rising costs of industrial refrigeration and process facilities such as food, beverage, and pharmaceutical motivate stakeholders to pay even more attention to optimize value while mitigating investment risks. Their concerns dictate a second or maybe third look at optimizing *life-cycle-risk* and *life-cycle performance*- - steps beyond *life-cycle-cost.* This Technical Bulletin considers the role of the *insulation system*[1] in these efforts since it has a material impact not only on life-cycle cost (material/labor capital cost plus long-term operation/maintenance costs) but also on life-cycle-performance and risk. Some key risks include:

- construction schedule delays
- operational energy/process inefficiencies
- outage/curtailments
- poor system resilience (e.g. from incidents, extreme weather events)
- inherently low *margins-of-error*
- inherent inflexibility (e.g. in process modifications, more cycling, expansion)

While the capital cost of the insulation system is relatively small compared to the rest of the facility, it is still substantive; and the additional impacts an insulant can have on the above bulleted parameters make the insulation system *Mission Critical.* On average, the cost of an *insulation failure*[2] during or shortly after Commissioning can lead not only to tens of thousands of dollars or euros in repairs for

[1] The Insulation System includes pipe coatings, insulants, vapor barriers, jackets, and the attendant mastics, adhesives, expansion joints, and so forth.
[2] Insulation Failure is defined as a plant curtailment or outage whose root cause was primarily insulation system related.

each occurrence, but also potential for violation of loan covenants at the critical moment when the Project Completion Certificate should be accepted.

Insulant Selection: Basic Impact on the Insulation System

All refrigeration and low-temperature process facilities need insulation on piping, tanks, and equipment. A typical large refrigeration or process facility may have thousands of linear feet of piping with diameters ranging from 3/8 to 12 inches, sometimes larger. Consider a sample of *100 linear feet* of *6-inch* diameter refrigeration or process pipe; depending on the insulant selected:

1) The volume of insulant can vary by 60%
2) Capital cost of the insulant (ignoring vapor barriers, jackets, etc.) can vary by >200%, and sometimes much more
    i. Note, the most expensive insulants do not necessarily deliver better thermal performance
3) The installed cost of the insulation *system* can vary by ~300%
    i. Weight of the insulants can vary by >700% Consider that a 10-inch carbon steel pipe can weigh 40 lbs/linear-foot; heavier insulants (such as cellular glass and calcium silicate) can weigh more than the piping, thus requiring unnecessary increased structural support cost while providing no incremental thermal insulation value
4) Insulants such as polyiso deliver the highest in thermal performance at much lower densities, and with less thickness

Note: ***there is virtually no correlation between cost per board foot and thermal resistance, and in some cases an inverse correlation exists; similarly, a higher weight insulant may or may not have better thermal resistance yet can be assumed to add to the cost of the installation.***

While there have been many engineer/specifiers who have opted to pay more money for poorer thermal performance simply because the insulant "is specified", owners and stakeholders are increasingly insisting on objective answers to "why"?

DUE DILIGENCE: INSULATION SELECTION

When insulation design engineers select an insulant on behalf of their client, their selection fundamentally dictates the performance/cost/risk profile associated with the entire *insulation system*. Each insulant requires different approaches to vapor barriers, expansion joints, accommodations for the overall weight of the system with stress on pipe hangars, as well as installation predicaments, long-term maintenance, and so forth. Additionally, there are new approaches to refrigeration and process facilities system design, including modularization and pre-insulation of pipe before shipment.

Unfortunately, some designers have not yet considered the impacts on the insulation systems necessary to support new refrigeration and process facility design approaches.

Unfortunately, insulation system designers often start with two initial choices: 1) select the insulant that was *qualified* by their organization years ago, or 2) consider *re-qualification* of the old and/or *qualification new-comers* in light of "*what we know today"*. Periodic re-qualification is increasingly critical due to a number of factors including changes in:

- specification standards (e.g. ASTM, EN, CINI),
- chemical formulations (such as the chemical's molecular components, or changes in additives such as fire retardants, catalysts, etc.)
- revised manufacturing methodologies
- varied manufacturing locations.

It is noteworthy that several "approval agencies" such as Factory Mutual (FM) and Underwriters Laboratories (UL) are plant-location-specific. In other words, an approval for a product manufactured at Facility X may not be accepted if it is manufactured at Facility Y - - even though formulations, equipment, etc. are *purported* as identical. In the latter case, for instance, an insulant manufacturing facility may relocate to (or near) a very large construction site in order to be more responsive/cost effective; yet most product certification entities including FM and UL require physical properties from each location of manufacture to be tested in order to remain certified. This ensures the product *delivered* is the same as the product *specified*. In all cases *due diligence* is paramount! The process of due diligence and selection of insulants is multifaceted; this Technical Bulletin hereafter examines a few of the components of due diligence that sometimes escape decision-makers/influencers.

LIFE-CYCLE PERFORMANCE/RISK

It is not possible to fully discuss life-cycle-performance/risk in adequate detail within this document; yet the insulant selection stage is a critical step in the process. Being *better informed* means *mitigating risks* and potentially *improving performance.* To be *better informed*, one must understand:

1) *What information is pertinent*?
2) *What information is factual and verifiable?*
3) *Is there full-disclosure of all pertinent facts*?

In other words, *better informed* does not simply mean *more information*.

What information is pertinent?

When considering *what is pertinent* there is the "must-have" of excellent thermal conductivity (k-factor, or *lambda*) - - the lower the better. Lower k-factors lead to less energy loss and improvement in process temperature control which can be critical in many applications. At the top of the list are:

1) *The k-factors across the spectrum of temperatures from the pipe to the ambient* (since k-factors improve at lower temperatures)

2) *Aged k-factors* (clearly defined by ASTM and other standards) are designed to offer an *apples-to-apples comparison* against insulants that do not age

    a. Insulants such as polyiso, phenolic, and others have very small *closed cells* containing blowing agents with superior thermal insulating properties (i.e. low k-factors), thus enhancing the thermal properties of the insulant [see *Thermal Aging*, below]

    b. Insulants that *do not age* either begin with "air" in their cells, or have air between fibrous or open cell structures, and will always have poorer thermal performance compared to closed cell foams that have low-conductivity gases within their cells

    c. When comparing insulants, *standard engineering practice* is to compare the *aged k-factor* of "insulants that age" against the thermal conductivity of the "insulants that do not age".

    d. *Cured* or *fresh* k-factors have no meaning within any credible *standard*

3) *Water Vapor Transmission (WVT) and Water Absorption (WA)* of the insulant without a vapor retarder/barrier. Higher WVT and WA results in degradation of thermal performance

    a. Many insulants (e.g. aerogels, expanded polystyrene, fiberglass) have very poor WVT and WA, yet come with a pre-applied vapor retarder that allows the supplier to advertise "low WVT and WA"; yet the fact is that there is no *second-line-of-defense* in the likely case of poor installation or mechanical penetration of the vapor retarder

    b. Polyiso has excellent WVT and WA, and thus inherently has a secund-line-of-defense against failure of a factory or field-applied vapor barrier.

4) *Other, depending on circumstance*

Temperature vs. k-factor

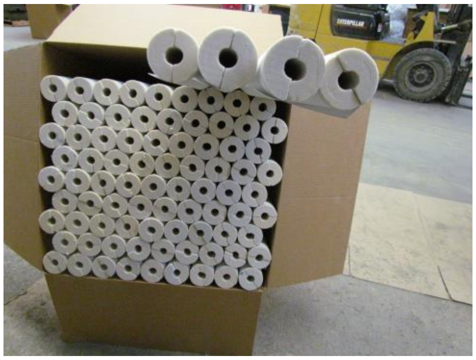
With respect to point #1, the testing standards/protocols increasingly demand measurement of k-factors across a variety of temperatures, whereas a common approach had been to compare insulants only at approximately 70-75°F. In fact, the latest ASTM C591 standard [the overall standard to which polyisocyanurate (polyiso or PIR) must comply] has now required k-factors measured across multiple mean temperatures from +200F to -200F. Understanding that the k-factor of most insulants improves at lower temperatures, thickness calculation programs such as 3E-Plus now incorporate a range of k-factors versus temperature for each insulant. ASTM C680 outlines an even more comprehensive and more accurate approach to thermal heat flux at different temperatures and across different geometries (such as cylindrical pipe).

Thermal Aging

With respect to #2, thermal aging is an interesting phenomenon and represents the process by which insulants using blowing agents such as hydrocarbons, hydrofluoroolefins, and others (rather than "air") lose some of their thermal resistance over time as a portion of blowing agents diffuse out of the cells. In other words, the "initial" (i.e. immediately after manufacture) k-factors of insulants such as polyiso are better than those reported in datasheets, but are not reported. Rather, "aged" k-factors <u>are</u> reported via ASTM testing protocols that take into account the diffusion of cell gases across cell boundaries. This is achieved by testing thermal conductivities after 180 days' exposure of a fully-exposed test specimen in a controlled ambient environment.

Note that in real-life applications, the diffusion of blowing agents is greatly inhibited by constraints to diffusion such as the pipe walls, vapor barriers, facing materials, and jackets. In virtually all applications, this suppression of in-situ aging ensures that the long-term k-factors of prevalent closed cell insulants such as polyiso are always better than the k-factors of other insulants that purportedly do not age.

WVT/WA



Regarding bullet #3, the other major *pertinent* properties of insulants are Water Vapor Transmission and Water Absorption. It would take several pages to cover these subjects in detail, but in summary, understanding these properties is paramount to understanding an insulant's ability (or inability) to prevent water vapor from reaching the piping. Additionally, any water absorbed into an insulant worsens its k-factor (reducing thermal resistance). The most interesting point here is that if a vapor *barrier* (meaning zero-permeability) sheet or mastic is properly applied over the insulation, the WVT and the WA of the *system* <u>should</u> each be zero. <u>Yet</u> in a conservatively-designed insulation system (which all refrigeration and cold process facilities installations should be) the designer must consider both errors in application of vapor barriers and/or breach of the barrier which can be caused by other factors such as mechanical abuse. Thus, a second-line-of defense is a large advantage; in other words, the insulant itself, exclusive of any vapor barrier, should be low-perm.

Other

Beyond these primary physical properties, others can of course be important. Higher compressive strength, for instance, is important when mechanical abuse is likely, and in circumstances where insulants carry load within pipe hangars. Flame/smoke ratings could be important when regulations invoke *indoor air plenum requirements*, which typically affects a small minority of refrigeration or process piping; and some engineers conclude a metal jacket virtually eliminates flame spread caused by insulation. Dimensional stability, weight, and flexural strength also have their impact on insulation system design and must be appropriately integrated by a qualified engineer.

Corrosion may also be a factor depending on process liquid chemistries or external environment. Dyplast's Technical Bulletin 0611 offers more detail on corrosion.

What information is independently verifiable?

At the top of the list for consideration by evaluating engineers is *third party testing* of physical properties - - followed closely by *listed approvals* supported by *periodic third party audit* by a *reputable* entity such as Factory Mutual or Underwriters Laboratory. Too often, manufacturers and suppliers quote physical properties measured within their own laboratories using sampling and testing protocols that may not comply with industry standards, a few of which are important to consider when trying to understand properties include:

- Sample curing/aging[3]
- Parallel versus perpendicular cut samples
- Sample selection (middle of sample, edge of sample, *skins* removed, an average?)
- Equipment calibration
- Date of last test, and have formulations or regulations changed since the last test
- Rationalization with test results of competitive products using different ASTM protocols.

[3] For instance, extreme yet unfortunately real examples include claims by some pour-in-place polyurethane suppliers of R-values of 7-9 (k-factors 0.14 to 0.11Btu.in/hr.ft^3.F) at 75F. Such claims should be examined with respect to 1) initial vs aged, and 2) date of the test versus formulation changes.

Regarding the first three bullets, it is readily possible to *bias* a test by testing samples that may not be representative of the product being sold. The chemical formulation of an insulant, for instance, can be *tweaked* specifically for a test sample to yield for instance higher thermal conductivity or strength measurements, yet while compromising other properties such as flame/smoke. That's why *third party audit* adds additional assurances; in the absence of third party audit the engineer/end-user should at a minimum ask relevant questions and insist on contractual representations from the seller of the insulant's properties.

With respect to the second-to-last bullet, *Date of the Test* is also more critical than one may conclude. Testing reports that are presented must reflect the current products being offered. Credible authorities such as FM, UL, and Miami-Dade not only require re-testing when insulant formulations or methods of manufacturing change, but also for renewals of certifications or even when the agency's own internal time intervals expire. Even minor adjustments to blowing agents, flame retardants, catalysts, etc. may alter physical properties. Decision-makers should inquire about any changes to inputs or manufacturing procedures that should justify product re-testing.

A final thought is that ASTM, EN, and other standards/protocols often make *apples-to-apples* comparisons challenging. For instance, ASTM prescribes water absorption tests for some insulants and "water sorption" test for others. Further complications arise when water absorption tests defined by ASTM for different insulants which vary from 24 to 96 hours.

In addition, requisite codes may not reflect rapidly changing regulatory and technology environments -- resulting in some cases far too lenient standards or at the other extreme unachievable standards. Other tests sometimes differ in their specifying *percentage based on weight*, while others specify *percentage based on volume*. The specifying engineer should clearly understand the essence of each testing protocol and more-so verify the *pertinence* and the *facts*. Using the WA example, if "≤1% WA" is, for instance, the specification, why is it pertinent without specifying per weight or per volume, and what if a 1% moisture gain in one insulant may materially impact k-factor while in another may not?

Is there full-disclosure of all relevant facts?

With respect to *full disclosure*, too often insulation suppliers and manufacturers simply do not expose key physical properties that they consider could be perceived as negative. As mentioned above, this could be the k-factors at various temperatures, the parallel strength versus the perpendicular, the dimensional stability (volume versus length) at low temperature, the actual WA or WVT of the insulant itself without the *skin* or the laminate, flexibility at low temperatures, cost per board foot, delivery times/flexibilities, prior successes and failures (plus root causes), and so on. Stakeholders should insist upon full disclosure - - or at a minimum disclosure comparable to competing suppliers. A specifier's or end-user's insistence on conformance ASTM or EN standards for low temperature applications and requisite compliance greatly mitigates these issues.

EXAMPLE CASE STUDY: POLYISOCYANURATE

A prominent process facility in the SouthEast USA, selected polyisocyanurate manufactured by Dyplast Products as the core of its insulation system. ISO-C1® was selected over competing polyiso's and alternative insulants for the project after balanced multi-value assessments by the turnkey contractor and the client. Key factors in their decision included:

- physical properties audited and validated by independent laboratory
- physical properties of ISO-C1 met or exceeded requirements set by ASTM C591
- ISO-C1 exhibited lowest aged k-factor profiles at the process temperatures as compared to competing, credible products
    - ISO-C1's k-factor improved significantly as temperatures drop
- the density of ISO-C1 at 2 lb/ft^3 made handling and shipping easier than 6 lb/ft^3 elastomeric, 7.5 lb/ft^3 cellular glass, or 10 lb/ft^3 aerogel, and structural engineers were able to minimize the number of pipe hangars - - also reducing cost
- customized bunstock sizing provided efficient shipping logistics and scrap minimization during fabrication
- availability of higher density polyiso (up to 6 lb/ft^3) provided the higher compressive strengths to support pipe hanger applications
- ability to fabricate blocks to close tolerances allowed for tight seams and joints
- flexibility and responsiveness in deliveries and technical advice enabled reduced costs, improved schedules, and enhanced relationships
- easy to handle and work in the field, with minimal breakage
- quick product turn-around and delivery (e.g. 2-3 days).

Dyplast's scope of work included polyiso insulation on more than 10,000 linear feet of piping. The insulation system consisted of single and double-layer insulation for piping with outside diameters varying in size from 1 to 10+ inches, covered with a combination of vapor barrier sheeting and mastic, enveloped in aluminum color-coded jacketing. Specifications required stringent adherence to validated physical properties for insulation system components, as well as specific standards for shop fabrication of shaped insulation segments, such as dimensional tolerances for hemi-cylindrical sections, pipe ells for small elbows, mitered sections for large elbows, and tees.

The ability to customize polyiso bunstock dimensions was clearly an advantage, since bun sizes could be matched to minimize waste as Dyplast cut the bunstock into blocks (”pipe chunks”) which were, in turn, sized for minimizing waste during shape fabrication. Optimally sized pipe chunks also allowed for efficient packing in transportation containers.

The demanding project schedule could be met only if parallel construction work was effectively executed, always carefully coordinated so that schedule savings could be realized at every opportunity. Dyplast’s flexible delivery schedule and ability execute *just-in-time* deliveries were critical to success. Communication feedback from Dyplast ensured that installation of the insulation system proceeded expeditiously and in sync with other contractors.

CONCLUSION

The essence of this Technical Bulletin is to engage a discussion. During this period of a global downturn, investments in new refrigeration and process facilities must focus in cost optimization, risk mitigation, and flexibility. Selection of the optimal insulant supported by its appropriate insulation system becomes *mission critical*. Engineers, specifiers, owners, and stakeholders should be increasingly vigilant regarding the facts, the relevance of the facts, and full disclosure as validated by independent parties. Specifications, standards, regulations, and technologies change. Insulant manufacturers either adapt to comply with the latest in order to support their client’s objectives - - or they choose to be parochial in advancement of short term interests. In the end it is the owner/investor who must either ask the tougher questions or become convinced their engineers are!