TECHNICAL BULLETIN 1020

INSULATION PERFORMANCE AT CRYOGENIC/COLD TEMPERATURES:

Logical Thinking: Part 1

Introduction

This is the first in a 3-part series of Technical Bulletins to discuss "Logical Thinking" when specifying mechanical insulation for cold/cryogenic applications. Our premise is that even insulation specifiers and engineers are challenged to understand and rationalize the available information on alternative insulants. A sample of topics to be addressed include:

- Different ASTM standards and test protocols for different insulants
    - For instance, how do you compare Water Absorption data when some require 2-hour immersion and some 96?
- Lack of physical property data at cryogenic/cold temperatures
    - For instance, what is the Water Vapor Transmission rate at -265°F (-165°C), considering the physics of the ASTM test at 75°F versus in-situ conditions?
- What are the real implications of "Aged" thermal conductivities?
    - *Aging* per ASTM is intended to facilitate an *apples-to-apples* comparison
    - An improved understanding may give you an edge.
- Suppliers that offer thermal conductivity/resistance based on radial geometry calculations (without proper caveats).
- To what extent does the "binder-on-the-shelf" that lists which insulants are "specified" actually reflect current reality?

Background

Dyplast's® Technical Bulletins are intended to provide objective information on insulation (mostly pipe) and foam core challenges. Our Qwik Guides typically offer abbreviated (one-page) technical perspectives, sometimes condensing Technical Bulletins. We strive to be objective and factual. If there are credible arguments that contradict our presentations, we invite them.

In this Technical Bulletin we begin a discussion about how the environment at very low/cryogenic temperatures is very different from the ambient conditions sometime set by the test protocols of many standards organizations (ASTM, EU, DIN, ISO, etc.). This is not a criticism of organizations, and more-so an endorsement of their ongoing initiatives to measure properties at varied temperatures.

This Bulletin is not intended to promote any particular cryogenic insulant over others, but rather to offer a *logical thinking* process that considers *consequences* that correlate to the performance of insulants for low temperature or cryogenic applications such as Liquid Natural Gas (LNG). It is not possible within this short document to address all physical properties or all low-temperature or cryogenic insulants, so we address the most important properties and briefly consider polyisocyanurate, cellular glass, aerogel, and elastomeric.

Logical Thinking

Imagining properties of materials at cryogenic temperatures can be somewhat *mind-bending*. Yet as Elon Musk (re: Tesla, SolarCity, and Space-X) is fond of saying, if your brain does not hurt at the end of every day, you're not doing your job. Albert Einstein, arguably the most accomplished physicist ever, was fond of *gedankenexperiment* (German for "thought experiment") - - which in essence considers *logical principles* for the purpose of *logically thinking* through *consequences*.

The approach in this article is somewhat along the lines of *gedankenexperiment*. In other words, the objective is to logically examine the complex issues that surround insulant performance at cryogenic temperatures - - a different approach than simply examining and comparing *numbers advertised in datasheets*, particularly those measured under ambient conditions with the hope or trust that they accurately represent and "apples-to-apples" comparison of insulant performance at -265ºF (-165ºC).

Buying Insulation versus Stainless Steel

Specifying insulation is not like specifying stainless steel wherein performance expectations are essentially defined by the elemental content of iron, chromium, molybdenum, magnesium, and so forth. To the contrary, the evaluation of alternative insulants using elemental analysis is neither realistic nor helpful; and even the comparisons based on published physical properties can be challenging for multiple reasons.

Furthermore, ASTM (et Al.) standards have the challenging job of defining testing protocols to determine physical properties for thousands of materials that will be used across varied environments (temperature, pressure, humidity, abuse, and so on). Traditionally, these protocols often tested materials at ambient conditions without considering actual in-situ performance; for example, many tests are at 75°F(24°C) when the installed pipe system will actually be at refrigerant or even cryogenic temperatures. But that is changing! For instance, years ago ASTM C591 (applicable to polyisocyanurate) began requiring thermal conductivities to be measured for temperatures increments from +200°F to -200°F (93°C to -129°C). CINI[1] similarly began requiring certain physical properties to be measured at -165°C (-265°F), including strengths and more.

Different Animals in the Zoo

Polyisocyanurate, cellular glass, elastomeric, and aerogel insulants are each very different, and physical properties often vary between manufacturers. Polyisocyanurate and cellular glass are each classified as rigid, closed cell

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[1] CINI (Committee INdustrial Insulation) is the International Standard for Industrial Insulation for LNG

foams, yet their chemistries (polyurethane versus glass-based) are very different, and polyiso can be 1/4th the density[2] of cellular glass which is 7-8 lb/ft^3. Elastomeric and aerogel insulants also have very different chemistries, and are reportedly flexible down to LNG temperatures. Cryogel-Z® is the heaviest of insulants at 10 lb/ft^3. Each of these insulants has quite different physical properties - - namely thermal conductivity, dimensions (without gluing), moisture resistance, strength, and so forth; and they behave differently at cryogenic temperatures. While they each have quite different thermal conductivities (see chart below) they are similar to the extent their thermal conductivities reduce as temperature decreases, although at different rates. So, let's begin by looking at thermal conductivities.

This *Most Important* Property: *Lambda*

Engineers often refer to thermal conductivity as either lambda (λ) or *k-factor*. Fortunately, when selecting an insulant for the vast majority of industrial applications the issues boil down to selecting the lowest life-cycle lambdas - - assuming parameters such as strength, dimensional stability, etc. meet the minimum standards set by code authorities or the system design engineers.

Lambdas of various insulants are typically referenced in corporate datasheets, and many suppliers are now offering lambdas at numerous datapoints from higher to lower temperatures. ASTM C591 (for polyiso) and CINI (for industrial insulation including LNG), now actually require such data. There are several cautionary notes, however, in addition to Chart Notes below:

- Different ASTM standards govern different insulants (e.g. C552 for cellular glass, C1728 for flexible aerogel, etc.); and those different standards may have different requirements, and may or may not:
    - Require lambdas across a broader temperature range
    - Specify actual testing at representative temperatures versus allowing an estimation via *polynomial equations* (use of the word 'declared' values should be questioned)
    - Allow internal test results, not verified by independent laboratory
    - Specify *maximum* lambdas
- Typical ASTM standards do not reference international EN or DIN standards, so if data have been tested according to such standards (listed as maybe 'equivalent'), the listed lambda values may not actually comply with ASTM
- If constraints on test conditions are not consistent with the real-life environment, in-situ lambdas may be worse (for instance, if compressive load on a Cryogel application exceeds 2 psi, the datasheet lambdas are inaccurate)
- It is common for certain insulant suppliers, particularly elastomeric, to list lambdas calculated on radial geometry rather than linear (established practice), thereby making lambdas appear better than they are
- Current, third party independent testing of lambdas is not only prudent, but essential.

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[2] Higher densities of polyiso are available when higher strengths are appropriate.

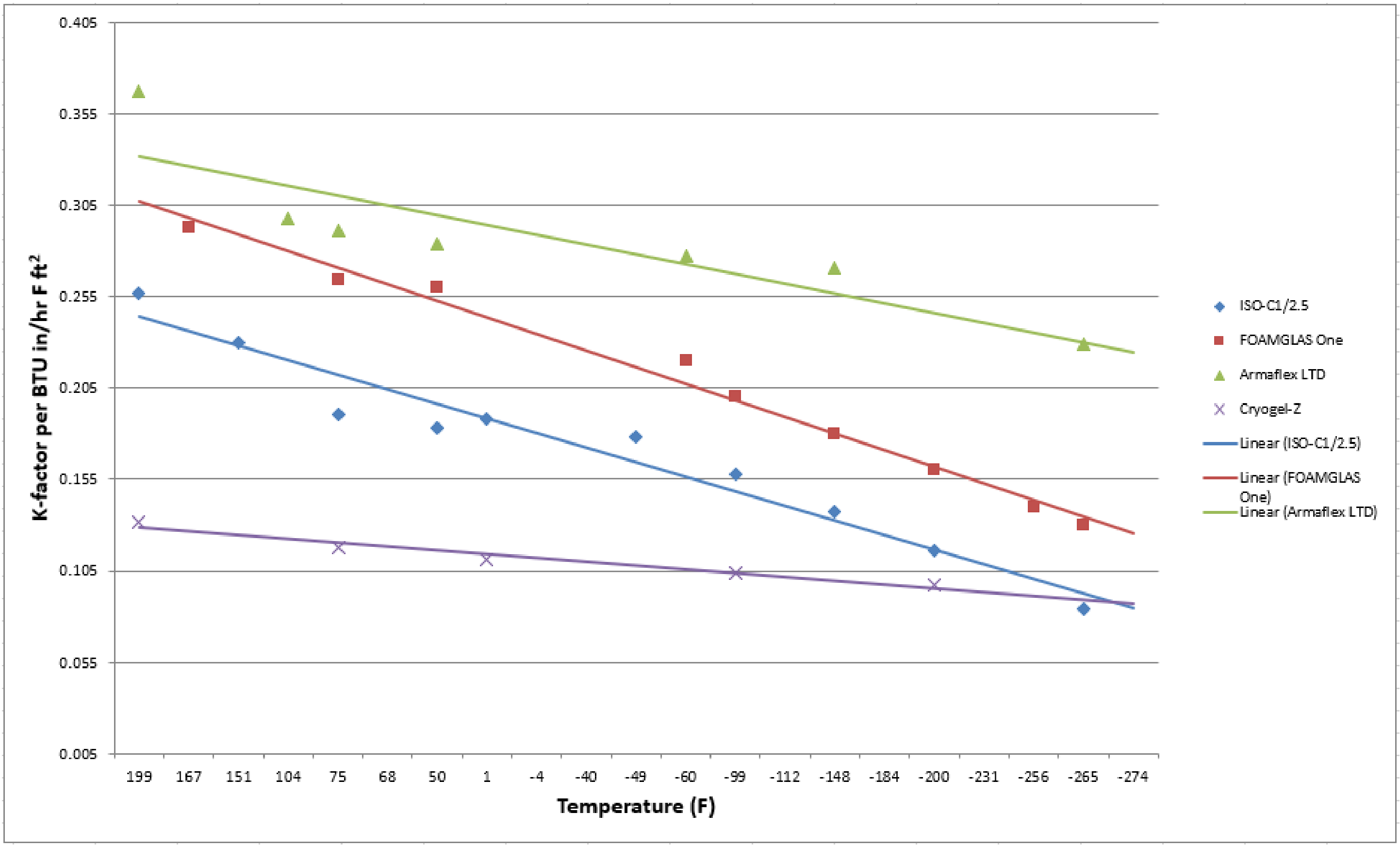
Logical thinking can be challenging given the complexity of the above variables, yet there is some guidance:

1. Insist on full-disclosure of data and the assumptions/caveats behind the data
2. Insist on independent, third-party verification of test results
3. Inquire about empirical evidence from actual installations with comparable environments, with opinions directly from the end-user, not just the supplier
4. Then, ask the tough questions, such as:
    a. What are the risks, causes, and mitigation issues related to degradation of lambda for each insulant (e.g. what if compressive loads on Cryogel are greater than 2 psi?
    b. When was lambda at each temperature last tested by an independent party?
    c. If the lambda of polyiso is better than cellular glass, and there is a vapor barrier and no concern over compressive strength, and cellular glass is appreciably more expensive, why use cellular glass?
    d. If elastomeric insulation lambdas are poorer than alternative insulants in cryogenic applications, and elastomeric is more expensive, why use elastomeric?
    e. Since insulant materials, themselves, are tested for flame spread and smoke development via ASTM E84, how do results accurately reflect the in-situ environment, with adhesives, mastics, vapor barriers, metal jackets, etc.? Better or worse?
    f. If the insulant must be glued together to achieve adequate pipe diameter, what are the risks?
    g. If aerogel insulants have air gaps between layers, what is the impact?

The following chart of Aged Lambda vs. Temperature was developed based on internet-accessible datasheets from leading manufacturers of the product-types: namely, Dyplast ISO-C1®/2.5 for polyisocyanurate, FOAMGLAS® for cellular glass, Armaflex® for elastomeric, and Cryogel®-Z for aerogels:

Chart notes:

1) *Readers are cautioned to request current, third-party verifiable information from manufacturers.*
2) *Lambda values may vary between manufacturers of "the same" product.*
3) *Trend-lines are linear representations of potentially non-linear functions; for actual lambdas between points, the manufacturer should be contacted.*
4) *Cryogel Z lambdas are measured at a compressive load of 2 psi, raising the question of the actual compressive load with multiple wraps.*
5) *Armaflex LTD lambdas reference "Declared acc. to EN 13787".*
6) *FOAMGLAS lambdas include the caveat "The values were determined by evaluating a polynomial…"*
7) *ISO-C1/2.5 polyiso lambdas were measured by an independent third party at each referenced temperature.*



The above chart suggests that polyiso and aerogel insulants achieve materially better lambdas than either cellular glass or elastomeric insulants. So why not logically exclude the latter from future projects, especially since earlier paragraphs in this article offered that thermal insulation's ultimate objective is to "insulate". Wouldn't *logical thinking* conclude that *thermal conductivity* "lambda" is the paramount indicator.

The obvious counter-argument is that "*extenuating circumstances*" may legitimately change the conclusion. While all *extenuating circumstances* cannot be addressed in this brief article, it may be instructive to consider examples such as the need for very high compressive strength, a *flexibility* prerequisite, or a requirement for zero smoke/flame performance per ASTM E84.

Aged Lambda (k-factor)

It is well known that thermal insulants using the *next-gen* blowing agents such as hydrocarbons and indeed *older-gen* fluorocarbons lose a small amount of their insulating value over time since air can displace the insulating gases within the cells. ASTM has designed a testing protocol (C591) that "ages" the target insulant for 180-days at approximately 24°C prior to measuring lambda. Thinking through the issues logically, one must consider the rationale applied by ASTM and other standards organizations striving to "level the playing field" amongst insulants being evaluated. Consideration must also be given to the fact that engineer/specifiers have for decades calculated a thickness for polyiso on LNG pipe based on *aged* lambdas. Any "*aging*" beyond predicted by ASTM protocols would have been clear, since failure would have otherwise resulted – the absence of which appears to validate the premise that material aging does not occur after installation in an LNG system. CINI specifies *aging* measurements per ASTM C591.

Engineering-minded folk may ask "to what extent does polyiso *age* at lower temperatures?" and/or "does a vapor barrier slow aging?" Good questions! Regarding vapor barriers and jackets, they will slow the aging process; and indeed thick insulant or multiple layers of insulant on an LNG pipe will also slow the aging of the inner layers.

Regarding lower temperatures, the *aging* process slows dramatically and can be considered as nil at cryogenic temperatures. In other words, in theory, if *initial* (i.e. prior to aging) polyiso is properly installed on cryogenic pipe, the inner layers of the insulant nearer the pipe may not age; and layers operating at less than ambient temperatures will age more slowly than they would at ambient temperatures.

Of course, this cannot be measured or guaranteed since factors such as outages, cycling up to ambient temperatures, and so forth would result in the insulant being above cryogenic temperatures for a portion of the time.

Summary

This first installment of a 3-part series on Logical Thinking in Low Temperature Environments has focused primarily on the complexities surrounding comparison of an insulant's thermal conductivity (k-factor or λ). The major conclusion is simply comparing the datasheets of alternative suppliers, can lead to inaccurate decisions, since some datasheets may not fully disclose data, and others have stated or unstated caveats that can render the data suspect or inapplicable to the intended application.

The good news is that we've included some advice in the prior discussion regarding what to look for in datasheets, and what questions should be asked of suppliers; and the application of Logical Thinking can help in making more optimal buying decisions.

Installment #2 will continue a discussion on some of the more interesting aspects of thermal conductivity - - such as across radial geometries, reasons for and impact of discontinuities in λ gradients, and we may begin touching on other physical properties such as water absorption at very low temperatures. The final installment #3 will delve deeper into physical properties as cryogenic temperatures are approached.