TECHNICAL BULLETIN 1120

INSULATION PERFORMANCE AT CRYOGENIC/COLD TEMPERATURES: Logical Thinking: Part 2

INTRODUCTION

This is the 2nd in a 3-part series of Technical Bulletins to discuss "*Logical Thinking*" when specifying mechanical insulation for very cold/cryogenic applications. It may be helpful to glance over the first page of Part 1, since we strive to avoid including redundant information in this Part 2. Dyplast's® Technical Bulletins are intended to provide objective information on insulation (mostly pipe) and foam core challenges.

In this document we continue a discussion about how the environment at very low/cryogenic temperatures is very different from the ambient conditions sometimes set by the test protocols of many standards organizations (ASTM, EU, DIN, ISO, etc.). We intend 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.

RECAP OF PART 1

In Part 1 we discussed the challenges in using physical property datasheets to make product selection decisions, since often:

- There may not be full disclosure of data
- Different ASTM standards are used to measure the same physical properties in different insulants
- There are sometimes caveats built into the data, stated and unstated, that make interpretation difficult
- ASTM often measures physical properties at *ambient* environmental conditions that likely may not represent the properties at very low or cryogenic temperature
- Insulant suppliers do not offer an *elemental analysis*[1] of the chemistries, nor would they be particularly enlightening.

The major topic in Part 1 was an examination of the thermal conductivity of an insulant, otherwise expressed as lambda (λ) or k-factor; and we delved into the variables involved in its measurement - - the primary being temperature - - yet also the impact of aging, as well as the influences of the entire *insulation system* with layering, staggering, vapor barriers, jacketing, etc. A chart of lambda versus temperature was inserted for four of the major low-temperature insulants.

HEAT TRANSFER

Moving beyond the Part 1 document issued on October 28th, we remind that each type of insulant of course has its own heat transfer complexities that may include 1) conduction through the solid or porous matrix (that may

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[1] Elemental analysis is a process where a sample of a material (e.g., chemical compounds) is analyzed for its elemental and sometimes isotopic composition.

contain cells of gas), 2) radiant heat exchange across the gases in the cells or spaces within the matrix, 3) and convection across cellular gases (containing either air, CO2, or blowing agents such a *low-lambda* hydrocarbons).

Additionally, the *apparent thermal conductivity* of the overall insulant depends on the type of gas in the closed cells, the size of the cells, the percentage of *open* cells, and the chemical composition of the *solid matrix* that contains the cells. For instance, it would appear *logical* that a glass-based matrix would have a poorer thermal conductivity than a polyurethane-based matrix.

Thus, it's simply not realistic to mathematically calculate an apparent thermal conductivity given the number of variables. Fortunately, actual empirical testing of heat transfer and lambda across the expected range of temperatures, verified by third-party independent labs, is available from credible manufacturers.[2]

RADIAL DIMENSION EFFECTS

It is important to address a mathematical approach used on datasheets from some suppliers (e.g. elastomeric[3]) that can be similarly problematic since it can make an insulant's thermal conductivity (or the inverse, thermal resistance or R-value) appear better than it actually is. Note first that ASTM and European standards typically test lambda across insulants cut into small flat sheets - - in essence a one-dimensional measurement. Since the actual heat transfer between the ambient environment and the cold pipe surface is radial, and thus two-dimensional[4], the ASTM and other protocols do not literally measure in-situ reality. Yet, our main point here is to alert readers to possible caveats in datasheets that can be deceptive - - such has measuring lambda linearly per ASTM but then using geometric calculations to make the lambda (or R-value) appear better - - making it difficult to make apple-to-apple comparisons. One insulant should not list lambdas calculated across radial geometries while others use linear geometries. The historical standard for insulant comparisons has been to do use linear geometries. Any insulant's lambda measured linearly can be converted to radial using geometric calculations - - thus, a radial calculation is not an indication of inherently better lambdas.

The mathematics of determining heat flux across radial geometries can be a bit daunting, yet there are many published approaches on the matter, and ASTM C680 provides recommended approaches, and even computer code to address the physical processes. Additionally, 3E-Plus[5] utilizes ASTM C680 protocols, yet is argued by some to be more conservative (maybe a good thing).

LAMBDA VS. TEMPERATURE GRADIENTS

Any insulant in contact with a pipe or vessel containing, for example, liquid natural gas at -265°F (-165°C) can be assumed to be at that cryogenic temperature within at least a few millimeters (maybe a few centimeters) of the

[2] Addressed more completely in Part 1 of this Technical Bulletin.
[3] See Dyplast Technical 0520, page 9 for an example comparison of insulants using radial calculations of lambda
[4] Ignoring very short runs of pipe where heat transfer could actually be 3-dimensional.
[5] 3E-Plus is free, publicly available software that approximates ASTM C680.

inner surface of the insulant - - and at the surface the temperature can be assumed to be closer to *ambient*. So, there is roughly a 340°F (+/-) temperature difference. The following questions are meant to invoke some logical thinking:

- Q: Is it logical to assume that the temperature gradient is linear across the insulant?
  - A: Yes, as long as the insulant is homogeneous! [in multilayer systems of the same insulant each layer should be tight-fitting without air gaps between layers; if there are air gaps, the apparent thermal conductivity will be worse and potentially nonlinear, but that is beyond the limits of this document to address]

- Q: What is the temperature gradient in a non-homogeneous insulant, such as in a hybrid (i.e. two different insulants layered on the same pipe) of polyiso and cellular glass?
  - A: The temperature gradient should be linear within each layer, with discontinuity in slope at the border of the insulants. [ASTM C680 addresses this issue, and essentially calculates temperature gradients and lambdas for each separate insulant: first an inner, and then an outer]

- Q: Which insulant would have a steeper temperature gradient - - the one with the higher or lower lambda?
  - A: The insulant with a lower (better) lambda! [consider for instance, that polyiso with a lower lambda may require a two-inch thick application on a small LNG pipe; thus the temperature may increase 340°F across two inches; whereas a poorer insulant that may require four inches on the same pipe would have a less steep temperature gradient]

- Q: Is the lambda at each temperature point known for each insulant?
  - A: Yes, possibly; but only if the selected insulant supplier has had lambdas measured by credible authority across a range of temperatures (for instance, in 50°F increments); it is within the margin of error[6] to assume the lambda is linear between the increments;

- Q: To what extent is the lambda gradient linear or non-linear?
  - A(1): In a hybrid system the lambda gradient will logically be non-linear;
  - A(2): Still, a tricky question even in a homogeneous insulant! For example: 1) the gases within insulant closed cells can liquify and even solidify at very low temperatures, which may have a noticeable (or even minimal) effect on lambda, depending on the cellular gas and the insulant; 2) the solid, or solid/matrix, the "air" in interstitial spaces, etc. each also have separate and distinct lambdas across the temperature gradient, yet they are too complex to mathematically model and must be determined with empirical evidence or testing

[6] Not only do ASTM 680 and 3E-Plus calculations incorporate a margin-of-error, but also the insulant is normally fabricated to the next higher increment of measure (for example, cut to the next inch of thickness)

- Q: Since the calculated thickness of pipe insulants is typically rounded up to the next increment (inch, half-inch, or centimeter), how much precision is necessary when calculating required thicknesses?
    - A(1): The related *increased margin of error* should mitigate any above non-linearities in lambda.
    - A(2): Another "*plus*" is that most credible engineering organizations have modeled thermal conductivity for multiple insulants across multiple temperatures and environments - - or have adopted publicly-available internet-based models such as 3E-Plus as sufficiently credible.

DUE DILIGENCE

It is logical to assume mechanical insulation projects within the specification and design stages clearly benefit from *due diligence* in order to achieve an optimal standard of performance. [also see Dyplast's Technical Bulletin on Commercial Quality Control]

While the cost of an insulation system is relatively minor compared to the capital cost of the project, it is one of the last steps in construction, prior to *Project Completion* - - and thus can become a critical financial liability if not implemented correctly. Then, also consider the lifetime commercial, safety, and environmental impact of a properly installed insulation system over its lifetime of operation.

Rather than simply pulling a large binder off-the-shelf to determine "*what has been specified"* in years past, why not reexamine the current data, empirical evidence, and recent lessons learned?

SUMMARY

This Part 2 of 3 mostly continued the theme of Part 1 with an expansion of the issues relating to thermal conductivity (lambda), since lambda is arguably the most important physical property to be considered when selecting the optimal insulant for a given application. We began with a brief discussion of heat transfer and its complexities, and concluded that the empirical approach is optimal to measure lambda rather than try to mathematically model.

The radial dimension paragraphs emphasized that calculating lambda using radial geometry creates a better lambda, yet is illusionary since it has nothing to do with the inherent properties on the insulant. Next, we ventured into an exercise on logically thinking about the linearity/non-linearity of thermal gradients across the insulation system, and extrapolated to the lambda gradients. The conclusion was that decision-makers who had more understanding of the physics of the heat transfer across insulation could ask better questions of their suppliers, and improve decision-making not only on insulation selection but also installation.

We ended on the importance of ongoing due diligence. The rapid advance of insulation products and changes to International Standards necessitate an ongoing skepticism regarding the information available to make the best selection of insulation.

Part 3 of this Technical Bulletin will investigate other physical properties (such as water absorption, water vapor transmission, strength, flame/smoke characteristics, and so on) at very low or cryogenic temperatures.