TECHNICAL BULLETIN 0520
Elastomeric vs. Polyisocyanurate Insulation In Industrial Refrigeration Applications

PURPOSE

Elastomeric and polyisocyanurate insulation are commonly used in refrigeration, HVAC, and chilled water as well as process applications across many industries such as food and beverage. While the essence of this Technical Bulletin is focused on refrigeration, and not process, the content and conclusions are applicable to process industries. Dyplast will shortly release a separate Technical Bulletin focused on Elastomeric vs. Polyiso insulation in Process Industries, such as Food & Beverage.

BACKGROUND

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.

The primary, demonstrable conclusion when we do comparisons has always been that polyisocyanurate (ISO-C1®) has better thermal insulation properties (combined with other physical properties that make thermal performance sustainable over the long term) than any other common pipe insulant[1], and typically at a lower installed cost. Yet we indeed acknowledge each alternative insulant may have a particular advantage in a particular application; for instance, if a compressive strength >150 psi is required in a pipe saddle, or if code requirements might demand 25/50 Flame/Smoke per ASTM E84.

Now as somewhat more information has become available from elastomeric manufacturers combined with the aggressive marketing from elastomeric suppliers for refrigeration applications, it is appropriate to offer within this document a significant update to and replacement of Dyplast's Technical Bulletin 0714 regarding elastomeric insulants compared to polyisocyanurate.

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

QUICK PERSPECTIVES

- This TB focuses generally on industrial refrigeration applications with cold lines in the approximate range from -40F to +40F, yet conclusions can generally be extrapolated well beyond this range.
- While the vast majority of industrial refrigeration facilities are made with carbon steel piping, there are certain applications where stainless steel is used, and infrequently, austenitic stainless steel.
- Polyisocyanurate (polyiso or PIR) insulants have many decades of demonstrably successful performance in refrigeration applications (and beyond, from -297°F to +350°F), across the breadth of metallurgies and process industries.

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[1] Aspen Aerogel's Cryogel® brand advertises better k-factors, yet cost and other disadvantages often apply (to be addressed in a separate Technical Bulletin).

- Elastomeric insulants vary in their chemistries, and thus physical properties (e.g. NBR/PVC, EPDM, etc.); products may be sheets or tubes - - each with different characteristics [read more below].
- Since elastomeric insulation has 30 to 47% poorer thermal conductivity when compared to polyiso (per ASTM C177 and C518), and when elastomeric insulation is commonly more expensive, the essential question is "why use it?"
- Some elastomeric insulant suppliers advertise that their product is "superior" in Austenitic Stainless Steel applications since it *may have* lower Leachable Chloride content than polyiso, and thus is acclaimed less susceptible to Stress Corrosion Cracking (SCC)[2], YET the facts are:
    - It is generally accepted that SCC occurs only at temperatures from 140°F to 250°F (a temperature range rarely approached in industrial refrigeration).
    - SCC is not applicable to the cold piping in refrigeration applications.
    - Note: neither non-austenitic stainless steel nor carbon nor copper exhibit SCC!
- At least two elastomeric insulant manufacturers have tables[3] of pipe sizes versus R-value (i.e. thermal resistance) given a particular insulant thickness - - in addition to the more traditional approach of providing thickness tables;
    - These elastomeric R-value tables are somewhat illusory (see next sentence) when they indicate R-values up to "20" for a two-inch thick insulant
    - These R-values are the result of calculating R-values based on a cylindrical geometry (a novel approach) rather than flat - - which is the ASTM standard convention for measuring thermal heat flux!
    - This is not necessarily a deceptive practice, yet using the same calculations, polyiso always has superior thermal performance! (see more on this later, including indicative tables)

PHYSICAL PROPERTIES

To quote from an elastomeric pipe insulation provider[4]: "Two commonly used synthetic rubber products, EPDM and NBR/PVC, are similar in appearance, but have very different performance properties that are not apparent just by looking at the two products…. [certain elastomeric] products may not deliver on what is claimed."

Elastomeric insulants come in tubes or sheets/rolls from several suppliers.

On the other hand, polyiso is a rigid thermoset foam that is manufactured as large, continuous rise bunstock in variable dimensions and densities. Higher densities have improved strengths, yet the chemistry is essentially the same and the thermal insulating properties very comparable. Buns are subsequently cut and fabricated into pipe and alternative shapes (e.g. for fittings) that fit tightly. [read more in Appendix 1]

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[2] Chloride stress corrosion is a type of intergranular corrosion and occurs in austenitic stainless steel under tensile stress in the presence of oxygen, chloride ions, and 'high' temperature.

[3] http://www.armacell.us/fileadmin/user_upload/Reference_Sheets_INS/AP_ArmaFlex_Tolerances_and_R_Values.EN.US.2017.pdf; and http://www.kflexusa.com/downloads/Technical%20Data%20Sheets%20-%20Insulation/K-Flex%20Insul-Tube.pdf

[4] https://www.aeroflexusa.com/about/we-are-different-and-better/epdm/

The most important perspective is that polyisocyanurate has an inherent thermal conductivity (k-factor) 30% to 47% better than elastomeric insulants, dependent on the elastomeric product, and at a lower installed cost. So let's start with k-factor:

Thermal Conductivity "k-factor"

Thermal conductivity is measured by either ASTM C177[5] or C518, which each test insulant specimens in a 'flat' configuration (i.e. a sheet). The aged k-factor of ISO-C1/2.0 as measured by C177 is 0.19 $BTU \cdot in/hr \cdot ft^2 \cdot F$ at 75°F, 0.18 at -50°F, and 0.16 at -100°F. K-factors of virtually all insulants improve at lower temperatures, yet at different gradients.

Elastomeric (NBR/PVC) k-factor at 75°F is nominally 0.245, and 0.235 at temperatures between 32 to 50°F. [the higher the thermal *conductivity*, the lower the thermal performance] Elastomeric (EPDM-based) k-factors are poorer at 0.28 and 0.278 at the same respective temperatures. In any event, end users should verify with the supplier. These k-factors are materially poorer when compared to polyiso, and thus elastomeric insulation over the pipe must be either thicker than a polyiso alternative; or from another perspective, a given thickness of polyisocyanurate will always provide more energy savings than elastomeric, regardless of temperature - - further lowering capital cost.

Thermal Resistance "R-value"

In a flat geometry (e.g. a wall) and such as measured by ASTM C177 and C518, the R-value is simply the inverse of k-factor. In a pipe (cylindrical) geometry the heat flux would be different if it could be measured in-situ, since the heat flow is radial from a smaller pipe surface area to the larger outer surface of the insulant. Certain elastomeric insulation suppliers attempt to make this adjustment via equations[6].

It is critically important to emphasize that when engineers and specifiers calculate the thickness of insulation required in a particular (apples-to-apples) scenario, their algorithms/calculations depend on the insulant's inherent k-factor! Their algorithms/calculations <u>then</u> incorporate the ***geometry*** of the application. 3E-Plus[7] is a classic example of such an algorithm.

The adjusted R-value tables offered by some elastomeric suppliers appear to circumvent industry-accepted thickness calculations by declaring very high R-values based <u>not</u> on the quality of the insulant, but rather on the geometry. -Again, the industry-standard is to calculate R-values on flat specimens to facilitate comparisons with other insulants. Calculations based on cylindrical geometry may be interesting to astute observers, yet potentially deceptive to others.

These R-value tables based on cylindrical geometry are not suitable for making an apples-to-apples comparison against other insulants, unless the alternative insulant R-values are calculated with the identical equations. In Appendix 2, we demonstrate that using the same cylindrical geometric calculations as used by at least one elastomeric supplier[8], the "adjusted R-value" of polyiso is in all cases better than that of elastomeric.

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[5] ASTM C177 is an absolute method and is the referee method designated by C591 for thermal conductivity measurements.

[6] This document does not address the accuracy of such equations, yet accepts the concept.

[7] 3E Plus® is a software program by the North American Insulation Manufacturers Association; while sometimes maligned, they offer agenerally conservative approach.

[8] http://www.armacell.us/fileadmin/user_upload/Technical_Bulletins_-_Insulation/TB01_CalculateR-Value.US.EN.2018.pdf

Indeed, a caveat by Armacell reinforces this conclusion: "*These specifications are based on the measurement methods employed by Armacell. Other methods may not result in the same values and cannot be used to determine if the product is within the given tolerance."

And another context provided by K-Flex is that their tables are not "R-value" but rather "R-value per square foot"; to be credible, this approach must be substantiated with *units-of-measure* and/or test methods that can be verified and compared to ASTM methodology.

Thus, the tables from some elastomeric suppliers that *adjusted R-values per geometry* should not be used to for thickness calculations.

Since polyiso has a better thermal conductivity than elastomeric insulants, under all circumstances it will always result in either thinner insulation walls, or greater thermal performance at a given thickness.

CORROSION and METALLURGY

This document cannot be a treatise on the extensive science surrounding corrosion and metallurgy. But to recap, the often-advertised advantage of elastomeric insulants relating to avoidance of Stress Corrosion Cracking has often-unstated or under-stated caveats!

- SCC only occurs on Austenitic Stainless Steels (ASS)[9]
    - If the pipe is not austenitic stainless steel there is no SCC
    - Non-austenitic stainless steels, carbon steels, and copper are not susceptible to SCC
- SCC only occurs at temperatures ranging from around 140°F to 250°F
    - In refrigeration applications, only a very small portion of ASS pipes/lines might be above 140°F and thus could be subject to SCC
- SCC requires a combination of four factors – 1) a susceptible material (in this case ASS), 2) a ***threshold*** of leachable chloride, fluoride, silicate, or sodium ions, 3) a presence of water, and 4) tensile stresses above a ***threshold***. If any one of these factors are eliminated, SCC initiation becomes impossible.
    - No elastomeric suppliers list the content of all ions listed in point 2 above (to our knowledge)
    - Some elastomeric insulant suppliers list chloride content; others do not
    - Certain elastomeric suppliers list leachable chlorides as "<0.05% water-soluble chloride ions" in accordance with DIN 1988 (a relatively old code of practice for drinking water installations)
    - Another elastomeric supplier lists leachable water-soluble chloride ions as ≤90 ppm per EN13468 and ASTM C871
    - SCC requires the presence of water, and if water is present there is a reasonable likelihood that the water/moisture itself will have a higher chloride content than the insulant; there should be no water or moisture at the pipe surface if the insulation system is properly installed

[9] Caveat: Stress Corrosion Cracking can occur in aluminum - - which is very rarely used in refrigeration applications

- During installation of the pipe and the insulation there is likely human ‘hands-on’ contact with the pipe could very possibly leave behind chlorides that exceed what may leach from insulation under these rare circumstances
- ISO-C1 products have a maximum leachable chloride content of 88 ppm per ASTM C871, with higher density foams having a value of <60 ppm
    - Again, leachable chloride content is only an issue on “hot” austenitic stainless steel pipe, and even then, only under confined conditions
    - Pipe coatings can eliminate SCC even on hot pipe

On the bigger picture, there are many factors beyond SCC relating to Corrosion Under Insulation (CUI) in refrigeration applications. A competent engineer should consider all CUI and not focus only on SCC. No metal pipe is immune from all corrosion threats, yet polyisocyanurate has been demonstrated to provide impressive corrosion resistance when installed in accordance with recommended installation practices. ISO-C1 has an exemplary performance history. A competent insulation engineer should be engaged to assess all potentially-related corrosion risks for a given circumstance. Dyplast addresses general corrosion in more detail in Technical Bulletin 0611.

Water Vapor Transmission

The Water Vapor Transmission (Permeance) of elastomeric insulation is typically advertised as low, and nominally <0.1 perm-inch (with some product brands higher). Thus, some elastomeric insulant suppliers indicate their product can be installed without a vapor barrier on small pipe in mild environmental conditions; yet the majority of suppliers note that “additional vapor barrier protection may be necessary when installed on low temperature surfaces or where exposed to high humidity conditions”. The majority of lower temperature refrigeration, particular in exterior applications, requires a protective covering for weather/UV protection, and typically with a net zero-perm WVT. Thus, both elastomeric and polyisocyanurate insulants will typically have a vapor barrier. And in such applications where the elastomeric suppliers argue that no additional external protection is required, an alternative polyiso application with a vapor barrier yielding a zero WVT will have substantially better WVT and still be more cost-effective.

Flame/Smoke and ASTM E84

Elastomeric insulants are typically advertised with an excellent Flame Spread Index (FSI) as ≤ 25 and Smoke Developed Index (SDI) ≤ 50 (in other words meeting a 25/50 rating per ASTM E84). Yet 25/50 is required in only a small portion of refrigeration applications. [Note: A 25/50 rating is required only when local codes invoke *indoor air plenum* requirements]. On the other hand, the vast majority of refrigeration applications require Class 1 per ASTM E84, with which polyiso readily complies.

Pipe Jacketing

Since both most elastomeric and polyiso insulants are cosmetically affected by ultraviolet radiation, and of course potentially susceptible to severe weather (hail, rain, etc.) and mechanical abuse by employees and contractors, pipe jacketing in refrigeration applications is appropriate in many circumstances. Since polyiso has compressive and other strengths in excess of elastomeric, polyiso may in fact require less jacketing.

SUMMARY

To echo the points made in Background and Perspectives addressed at the top of this document, the primary demonstrable conclusion is that polyisocyanurate (ISO-C1) has better thermal insulation properties than any elastomeric on the market - - and at a lower installed cost!

We have herein comprehensively explained that the two often-advertised *advantages* of elastomeric are in fact not material advantages when compared to polyiso:

- SCC is a concern only in a narrow set of circumstances, and using elastomeric insulants to address SCC (or an unnecessary concern over SCC), is expensive - - with polyiso being a better and more cost-effective alternative.
- Adjusted R-value tables used by some elastomeric suppliers *are just that* - - adjusted to create an illusion of superior performance when in fact the tables have little to do with the actual performance of the insulant and rather on the geometry that applies to any insulant.

To avoid redundancy in further explanation, simply click SCC or R-values.

As always, if Dyplast has made an error, or misrepresented facts, we invite constructive criticism and will adjust this Technical Bulletin on our website, and re-issue this document if material.

Appendix 1: Product Descriptions

Figure 1: Polyiso exiting the *tunnel*

WHAT IS POLYISOCYANURATE?

Polyisocyanurate (a modified polyurethane with improved physical properties) is produced as the result of a chemical reaction between polyol and isocyanate. Polyiso has a higher percentage of isocyanate to improve k-factor, dimensional stability, and flame/smoke properties.

Polyiso bunstock for mechanical insulation is produced by pouring a multi-component liquid onto a moving belt. As the liquid travels through the "tunnel" it undergoes a chemical reaction and rises into a "bun" constrained on three sides but not on top; nominally 48 inches wide by 30 inches high; dimensions on higher density bunstock may vary. The foam is cured and subsequently cut into sheets or blocks that can be fabricated into virtually any shape and size for small to very large pipe insulation. Dyplast's ISO-C1 has a standard temperature range from -297°F to +300°F; ISO-HT is effective up to 350°F. Polyiso densities typically range from 2.0 to 6.0 lb/ft^3, with 2.0 to 2.5 lb/ft^3 typically used for low temperature pipe and equipment, and 6.0 lb/ft^3 used for pipe hangars and applications where higher strengths are appropriate.

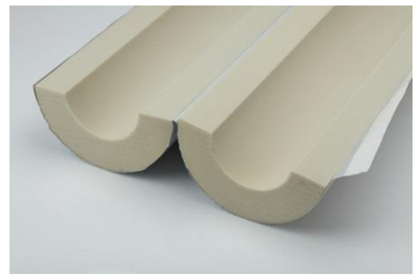

Figure 2: Polyiso "clamshell" with factory-installed vapor barrier

WHAT IS ELASTOMERIC?

Elastomeric insulation is a "rubber" compound that is flexible and can be supplied as a tube, with or without a slit, that can be applied around pipe up to 8 or sometimes 10 inches in diameter (depending on supplier). Elastomeric insulation can also be supplied in flexible sheets that can be wrapped around larger diameter pipe, or over refrigeration fittings and equipment. The three main components used in the manufacturing of elastomeric closed cell foam insulation predominantly include the following, yet end-users should request clarity on the product to be delivered:

- Synthetic rubber blends, which can vary considerably
- Nitrile butadiene rubber in combination with polyvinyl chloride (NBR/PVC)
- Ethylene-propylene-diene monomer (EPDM)

Figure 3: Elastomeric sheet

At least one supplier recommends NBR/PVC for insulation thickness under 1.5 inches, and EPDM synthetic rubber for insulation thicknesses above 1.5 inches. NBR/PVC and EPDM each have different chemistries and thus different thermal as well as physical properties such as water vapor permeability, water absorption, strength, maximum temperatures, and so on.

Figure 4: Elastomeric "tee"

In the manufacturing process components are combined in a large mixer, typically in batches of 500 pounds or more. The mixture is then put through extruding equipment to form a particular profile or shape, typically either a round tube or a flat sheet. The profile is heated in an oven to a specific temperature, a process that causes the chemical foaming agent to change from a solid to a gas. When this occurs, tiny air pockets (cells) form. It is then cut to size and packaged for shipment. Elastomeric foams can have a density ranging from 3 to 6 lb/ft^3, and are typically green, black, gray, or can be white in color.

There are numerous manufacturers of elastomeric insulation, with many branded products beneath each manufacturer, with physical properties varying considerable between products. End-users, engineers, and contractors are cautioned to be sure of the physical properties of the insulant to be purchased.

Appendix 2: Nominal R-Value Tables Adjusted to Cylindrical Geometry[10]

1" Thick Insulation Walls*

Pipe	Pipe ID (inches)	Calculated R-value** ISO-C1	R-value Elastomeric from ArmaFlex datasheets
copper	1	9.3	7.2
copper	1.25	9.3	7.2
copper	1.5	9.3	7.2
IPS	1.5	9.0	6.9
copper	2	8.7	6.8
IPS	2	8.4	7.1
copper	2.5	8.3	6.5
IPS	2.5	8.1	6.8
copper	3	8.1	6.3
IPS	3	7.9	6.6
copper	3.5	7.9	6.2
copper	4	7.7	6.1
IPS	4	7.6	6.4
IPS	5	7.3	6.2
IPS	6	7.2	6.1
IPS	8	7.0	5.9
IPS	10	6.9	5.8

2" Thick Insulation Walls

Pipe	Pipe ID (inches)	Calculated R-value ISO-C1	R-value Elastomeric from ArmaFlex datasheets
copper	1	19.8	14.5
copper	1.25	18.8	13.7
copper	1.5	17.9	13.1
IPS	1.5	17.3	12.4
copper	2	16.7	12.2
IPS	2	16.1	12.3
copper	2.5	15.9	11.6
IPS	2.5	15.4	11.7
copper	3	15.2	11.1
IPS	3	14.8	11.2
copper	3.5	14.8	10.7
copper	4	14.3	10.5
IPS	4	14.0	10.7
IPS	5	13.5	10.2
IPS	6	13.1	9.9
IPS	8	12.6	9.5
IPS	10	12.2	9.2

Notes:

* 1 inch and 2 inch thick insulation walls were selected as examples; other insulation thicknesses reflect the same trends since ISO-C1 has better k-factors

** R-values units are $ft^2 \cdot °F \cdot h/BTU$; calculated using logical application of Armacell's formula $R = [r_2 * (\ln (r2/r_1))] / k$, where r_2 is outer OD of insulant, r_1 is ID, and "ln" is the natural log[10]

*** K-Flex lists *comparable* R-values in their Insul-Tube datasheet

**** R-values can vary based on actual pipe/tube OD, insulant ID, tolerances in fabrication of insulation thickness, etc.

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[10] Dyplast does not intend that these R-values be used in any calculations involving thickness or performance requirements. Dyplast does not necessarily endorse this particular equation for *R-value calculations adjusted for cylinders*, yet uses them to offer an apples-to-apples comparison with certain elastomeric suppliers.