TECHNICAL BULLETIN 1128[1]

Mechanical Insulation

In Typical Refrigeration Applications

PURPOSE

As operating temperatures of mechanical equipment and piping systems drop, increased diligence must be exercised to optimize the insulation system's performance and mitigate risks of future deterioration. When specifying and installing an insulation system for pipes or equipment operating at refrigerant temperatures (e.g. -70°F to 32°F) *cutting corners* or *rationalizing compromises* is imprudent since the operating costs and risks far outweigh any reduced capital costs; and it is important to note that the *best systems* are typically not the *most expensive systems*.

The purpose of this Customer Bulletin is to simplify what can be often perceived as a complicated process by offering objective information on the most important step: the selection of insulants and vapor barriers. The repercussions of a poor selection at this stage cannot be mitigated during later steps.

A comprehensive discussion of the various physical properties of insulation alternatives is beyond the scope of this bulletin - - and fortunately such a detailed analysis is unnecessary. In fact, the big picture too often gets lost in the debate over issues of little impact.

It is important to also note that "what is not said" can be more important than "what is said"; thus we strive for full disclosure while also striving for brevity. As always, if the reader of this Bulletin believes we have erred or misrepresented facts, we welcome suggestions.

SUMMARY

Manufacturers and suppliers of mechanical insulation and system accessories typically provide datasheets listing a host of physical properties. This Bulletin offers that the importance of thermal conductivity (k-factor[2,3]) and water vapor transmission (WVT[4]) of the insulant typically far outweighs the impact of other physical properties. Thus refrigeration system specifiers, engineers, procurement managers, contractors and owners should focus heavily on these two physical properties when comparing alternative insulation materials.

[We note a caveat, of course, that there may be specific requirements for a particular application that may otherwise influence the decision - - discussed later in this Bulletin.]

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[1] An Update to Customer Bulletin 0411.

[2] Simplified, the k-factor (thermal conductivity) is the measure of heat that passes through one square foot of material that is 1 inch thick in an hour per unit temperature difference. The lower the K value, the better the insulation. C-factor is the k-factor divided by the thickness of the insulation material. The R-factor per inch can be determined by R=1/k. The higher the R factor, the better the insulation.

[3] The issue of aged versus initial k-factors is addressed later in this document.

[4] The Water Vapor Transmission Rate of a material is referred to as its permeability, stated in perm-inches; independent of the materials' thickness. Dividing the permeability of a material by its thickness gives the materials' permeance, stated in perms. ASTM E96 measures a material's rate of Water Vapor Transmission per unit area per unit of vapor pressure differential under test conditions, expressed as perm-inches (grain/hr·ft^2·in Hg·in) of thickness.

Also note that Water Absorption (WA) is not considered as important as “k” and WVT for two reasons:

1. A good zero-perm vapor barrier and a protective jacket should prevent external water from coming in contact with the insulant, even in a rainstorm.
2. For the insulants that may be under consideration for a mechanical piping in a refrigeration application, a low WVT insulant also has low WA (i.e. they are linked).

In essence, compromising the k-factor of the insulant costs a lot of money via energy losses as well as process inefficiencies. Specifiers and end-users should strive for a credible cost vs. benefit analysis before thermal conductivity is sacrificed for the sake of another physical property.

Vapor barriers, on the other hand, are the first line of defense against moisture intrusion - - with the insulant as backup defense. Since there are now several suppliers offering zero-perm sheets, tapes, and mastics, specifiers and owners have no reason to compromise by selecting a *vapor retarder* with poorer perm ratings. The permeance of the insulant, as a backup to a damaged or a poorly-installed vapor barrier, is also a critical factor when selecting an insulant since over the life of the system it may be a *lifesaver*.

Of the insulant and vapor barrier alternatives available, Dyplast’s ISO-C1® polyisocyanurate is the obvious choice for refrigeration applications. ISO-C1’s combination of 5.7 R-factor per inch (at 75°F) and WVT permeability of 1.65 perm-in is superior to any other alternative insulant, which is each handicapped by either a lower R or a higher WVT. And for vapor barriers, DyPerm™ Wrap and Tape offer zero-perm performance, besting the better-known alternatives.

K-FACTOR DISCUSSION

1. The k-factor of an insulation system is fully dependent on the thermal efficiency of the insulant itself, with negligible contribution from other components of the system. Other components have primarily *protective roles*, meaning failure of any may degrade the performance of the insulant.
2. While the capital cost of the insulation material is important, the thermal insulating efficiency of the material can have the dominant impact via cost savings over the long term, through energy savings as well as process efficiency:
    a. Electricity/Fuel Consumption: energy loss in a refrigeration system costs money, and with the price of energy rising, the operating costs over the long term can be significant. Customer Bulletin #0111[5] compared the energy losses of refrigerant pipe insulated with polyisocyanurate versus extruded polystyrene. One example demonstrated that over 20-year period, the polyisocyanurate-insulated system would save $40,000 for each 100 linear feet of 6 inch pipe when compared to extruded polystyrene (XPS).
    b. Process Efficiencies: Refrigeration processes have design specifications limiting pressure and temperature drops across the system. Pipe size and other restrictions are part of the

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[5] Bulletin #0111: Polyiso vs. XPS; www.dyplastproducts.com/Customer_Bulletins/CUSTOMER_BULLETIN_0111.pdf

design process, yet insulation plays a comparable role. An enlightened insulation system specification and proper installation will ensure optimal performance.

3. The k-factor will determine how many inches of insulation will be required to achieve condensation, energy loss, or process efficiency objectives. Greater thicknesses of insulation result in:
    a. More board feet of insulant, thus incrementally increasing cost.
    b. Incrementally larger sheets of vapor barrier and jacketing, plus the various sealants, tapes, and so forth.
    c. Incrementally greater weight, affecting pipe hangar design and quantity.
    d. Inability to properly insulate "nested piping" (pipes that are close together, and may be carrying liquids/gases of different temperature)
4. Aged K: Certain insulants (e.g. polyurethane, polyisocyanurate, and extruded polystyrene) utilize blowing agents other than air in order to improve k-factors. These blowing agents diffuse out of the foam over time, thus degrading k-factors slightly; but the rate of diffusion varies considerably with the chemistry, cell size/quality/structure, type of blowing agent, temperature, and impediments to diffusion such as vapor barriers. ASTM established a conservative standard of 6 months of aging at 75°F before measuring "aged" k-factor. As a conservative measure, specifiers, engineers, and end-users should utilize the aged k-factors at 75°F to compare insulants, even though at the lower temperatures experienced in a refrigeration application, the k-factors will be better and diffusion of blowing agents will be impeded or even halted particularly with vapor barriers sealing the foam insulation. On a final note, even when polyisocyanurate is "fully aged" (however defined) its k-factors are better than those of most insulants, particularly polystyrenes.

Table 1: Ranking R-factors of common insulants (*Aged*, unless noted)[6]

Insulant	**R-factors per inch**	**Comment**
Phenolic	6.6	Unclear whether initial or aged k-factor; -292 to +248°F
Polyisocyanurate	5.3-5.7	Varies among manufacturers. Service Temps -297 to +300°F
Expanded Polystyrene	4.3	Melts above 165°F
Extruded Polyethylene	4	-200 to +200°F
Extruded Polystyrene	3.9	Melts above 165°F
Elastomeric	3.6-3.8	up to 220°F; Density Varies from nominal 2 to 6 lb/ft^3
Fiberglass	3.8	Generally not used for applications <-20°F due to combination of low R-

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[6] Although k-factors of the "same" material can vary between manufacturers, average reported *aged* k-factors at 75F at typical densities were used. For some materials, k-factors improve at lower temperatures.

		VALUE AND HIGH WVT AND WA
CELLULAR GLASS	3.5	HEAVY: NOMINALLY 7 LB/FT^3

WATER VAPOR TRANSMISSION DISCUSSION (WVT per ASTM E96)

a. First it is important to note that the primary defense against WVT is a properly installed, zero-perm vapor barrier system, which generally includes sheeting, tapes, and mastics. The insulation is the second line of defense in case the primary vapor barrier is damaged -- which over a 20 year life may happen (e.g. installation mistakes, stepping on pipe, poor insulation repairs after maintenance, etc.).

b. The environment outside the pipe insulation system varies in temperature and humidity, not only regionally but daily. Higher humidity and higher temperature result in higher *vapor drive*. As is always the case, nature will try to equalize an imbalance, which means that the water vapor will try to migrate from a location of higher concentrations (outside the pipe jacket) to a location of lower concentrations (on the surface of the pipe) - - unless impeded; and from warmer to colder surfaces.

c. Vapor drive in refrigeration applications will result in condensation on the pipe, valve, or equipment surface - - possibly resulting in inoperability or corrosion.

d. Condensation or ice on the outside of the insulation jacket is equally troubling, and possibly also indicative of inadequate quality or thickness of insulation.

e. There may be some understandable confusion over the impact of WVT versus Water Absorption (WA per ASTM[7] C272, C240, or D2842) on insulation performance. Water absorption is indeed a problem in fibrous insulations such as fiberglass, calcium silicate, mineral wools, etc.; such insulants depend heavily on air pockets within the fibers to create the resistance to heat flow. When moisture collects within these spaces, the k-factors can deteriorate significantly.

f. Water Absorption is less of a problem, although may be a minor factor, in closed cell foams (e.g. polyiso, phenolic, cellular glass, and some polystyrenes) where there are very few interstitial "pockets" where water could congregate and thus provide thermal conduits.

g. WVT improves with insulation thickness. If an insulant's permeability is 1.65 perm-in, a 2.5 inch thick pipe half-shell would have a permeance of 0.66.

TABLE 2: WATER VAPOR TRANSMISSION FOR DIFFERENT INSULANTS

INSULANT	WVT (PERM-IN)	COMMENT
CELLULAR GLASS	0	WATER ABSORPTION (WA) = 0.2%[8]
EXTRUDED POLYETHYLENE	0.048	WA = 0.05%
PHENOLIC	0.9	WA = 0.5% BY VOLUME

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[7] Various ASTM standards/tests vary in duration and conditions, and it is difficult to establish "apples-to-apples" comparisons. Yet Water Absorption in insulants used in refrigeration applications is generally not the problem.

[8] Manufacturer notes the only moisture retained is that adhering to surface cells after immersion.

Elastomeric	0.2 to 1.0	Varies by manufacturer
Extruded Polystyrene	1.5	WA = 0.5%
Polyisocyanurate (ISO-C1®)	1.65	WA = 0.04% (Note: better than cell glass)
Expanded Polystyrene	2.0	WA = 2%
Polyisocyanurate (Trymer 2000XP®)	4	WA = 0.7%
Fiberglass	High[9]	WA = ?[10]

CAPITAL COSTS

Earlier in this Bulletin, a stated position was that the *best insulation* does not equate to the *most expensive* (e.g. capital cost). Readers are also cautioned against relying on another sometimes-used metric of *Cost per R-Value,* since for example a fiberglass insulant may have the lowest cost per "R", yet will likely lead to quick failure in a refrigerant system.

Deducing price-points for the various insulants is challenging since not only do prices vary among manufacturers of the same insulant, prices can change quickly over time as the cost of raw materials, sometimes driven by the cost of oil, vary. Yet it may be instructive for us to offer a relative comparison of insulant costs (excluding installation) as an objective observer would conclude today. Readers of this Bulletin are cautioned to do their own price-check, and should consider the following table only as *food for thought*.

Table 3: Ranking of Different Insulants Relative To Capital Cost of Material[11] (per board foot) from highest to lowest cost

Insulant	**Cost**
Cellular Glass	Highest
Extruded Polystyrene (XPS)	
Phenolic	
Elastomeric	
Extruded Polyethylene (e.g. CryoFlex™)	
Polyisocyanurate	

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[9] Water vapor transmission for fiberglass insulation is not quoted unless a liner (skin) is involved, and then only the WVT of the barrier is typically quoted.

[10] Water absorption in fiberglass is measured by different ASTM standards than the other insulants. Although water absorption in fiberglass pipe insulation has traditionally been expressed as a concern, some manufacturers claim a Water Sorption of <1% as measured by ASTM C1104.

[11] "Installed costs" include installation and can thus vary significantly due to many factors. For instance, insulants with better k-factors require less board feet of material (small profiles), thus equating to lower usage of vapor barriers, sealants, mastics, jackets, etc.

EXPANDED POLYSTYRENE (EPS)	
FIBERGLASS	LOWEST

CAUTION

1. Based on the criteria presented herein, phenolic foam insulation may appear to be the optimal choice assuming *fully-installed capital costs* are reasonable and claims of k-factors and WVT are accurate. Since the initial cost of phenolic insulants are quite high, specifiers and end-users are cautioned to ensure the stated k-factors from suppliers are “aged”, that WVT is defendable, and that all properties are independently verified. Although continual improvements in the formulations of phenolic foam insulation products are being made, phenolic foams have a reputation of exhibiting low flexural strength (are very brittle) and high friability (tendency to crumble). This can lead to high breakage during fabrication/installation/use, labor complaints during handling, and poor adherence of adhesives and mastics.

CAVEATS

As mentioned earlier, there may be unique circumstances where a particular characteristic of an insulant may sway the decision regarding *optimal*. The following are examples:

1. Flame spread index/smoke developed index per ASTM E84
    a. Most refrigeration applications require Class 1 FSI/SDI ratings[12]. In the rare cases that building codes require 25/50 ratings, the selection of insulants may be limited to cellular glass, elastomeric, or phenolic - - each of which has deficiencies in other areas that will degrade performance (e.g. k-factor, water vapor transmission, etc.). The end-user is cautioned to examine claims by the supplier, and should expect third-party verifications.
2. Compressive Strength
    a. Insulation for pipe hangars as well as piping that may be subject to mechanical abuse which may require higher compressive strength - - which very generally equates to lower k-factors. In such case, the end-user should evaluate the k-factor versus strength.
3. Chemical Resistance
    a. Note first that the chemical resistance of the jacketing and the vapor barrier is likely more important than the chemical resistance of the insulation.
    b. Chemical resistance is an overly broad descriptor, and at the highest level is broken into solvent-based and water-based. *Solvents* can include a large number of chemicals which cannot be addressed in this Bulletin. Commercially available water-based mastics and adhesives are generally benign. Cellular glass and fiber glass are likely the most resistant to solvents and other chemicals, followed very generally by polyisocyanurate,

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[12] Customer Bulletin #0511 Questions You Should Ask When Selecting Mechanical Insulation; www.dyplastproducts.com/Customer_Bulletins/CUSTOMER_ BULLETIN_0511.pdf

polyurethanes, elastomerics, polyethylenes, and polystyrenes. End-users should evaluate the likelihood that the material would be exposed to any particular chemical.

4. Corrosion Under Insulation
    a. Corrosion is typically the result of water making contact with the pipe - - which should not be possible with a properly-selected insulation and vapor barrier.
    b. Chloride stress corrosion of certain stainless steels[13] generally requires both temperatures above 140°F and the presence of chlorides. The most relevant, rarely quoted physical property of insulants is "leachable chlorides", yet in refrigerant applications it is unlikely that requisite water is present and also unlikely that the chlorides are *leachable* at the service temperatures.
    c. Corrosion, when considered likely, can be readily controlled by applying epoxy coatings.
5. Service Temperature Cycling
    a. In circumstances where service temperatures in a refrigeration application may cycle to temperatures above 165°F or higher, a number of insulants will either be damaged or performance will deteriorate - - and are thus unusable.
    b. Table 1, above, lists maximum temperatures for susceptible insulants.
    c. Dyplast's ISO-C1 polyisocyanurate is suitable up to 300°F, and its sister product ISO-HT is suitable for long term use at 400°F.

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[13] Bulletin #0611 Corrosion: http://www.dyplastproducts.com/Customer_Bulletins/CUSTOMER_BULLETIN_0611.pdf