\[ U = \frac{1}{R_T} = \frac{1}{R_{se} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdots R_{si}} \]

\[ \lambda_{COP} = 0.0037 \text{ W/(m·K)} \]

\[ \lambda_{total} = \lambda_{solid} + \lambda_{convection} + \lambda_{radiation} \]

\[ k = A \cdot e^{-\frac{E_A}{R \cdot T}} \]

\[ \Psi = \frac{\Phi_{total} - \Phi_{undisturbed}}{\Delta T \cdot l} \]

\[ \lambda_{eff} = \lambda_{COP} + \Psi \times \text{Thickness}_{VIP} \times \frac{\text{Perimeter}_{VIP}}{\text{Area}_{VIP}} \]
Morgan Advanced Materials

Morgan Advanced Materials is a world leader in advanced materials and is committed to building a sustainable competitive advantage in attractive markets with truly differentiated products and services underpinned by world-leading technology. We supply innovative products which enable our customers’ products and processes to perform more efficiently, more reliably and for longer.

About Porextherm

Porextherm is a part of Morgan Advanced Materials – Thermal Ceramics. Porextherm is a provider for innovative thermal insulation solutions. Since 1989 we have continuously expanded our core expertise in microporous insulation systems and build a broad portfolio of partly patented products and processes. Based on our own research and engineering we have developed an impressive variety of insulation products, which are manufactured in our modern state of the art facilities in Kempten, Germany.

Main application areas for VACUPOR®

- Cooling appliances
- Building and Construction
- Temperature controlled packaging
- Industry
- Transportation and Logistics
- Cryogenic
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Please Note:
The technical approval No. Z.23.11-1662 is valid, only for the VACUPOR® types mentioned there in. Only these products meet the increased demands on fire protection, which are necessary to obtain an building authorities approval. This is achieved through a modified version of the barrier film.

In the field of building and construction industry in Germany, all other VACUPOR® versions are not approved by the building authorities. These VACUPOR® versions may be applied in areas where a Vacuum Insulation Panel is treated as an unregulated construction product, if an admission on a single case exists or will be obtained.

The thermal conductivity values declared for these VACUPOR® versions FP just describe the value of the Vacuum Insulation Panel under the mentioned conditions, measured in the center of the panel. The measured value does explicitly not correspond with the rated value, determined by the DIBt and may not be used in Germany for the implementation of thermal calculations for buildings.
Vacuum insulation panel technology

What is vacuum insulation?
It has been known for a long time that the insulation values of some materials can be significantly improved maintaining them in an evacuated environment. The choice of insulation materials in combination with the degree of vacuum applied to them, very much determine the final insulation values of a VIP. In order to understand where the extreme insulation values of a VIP are derived from it is worth reviewing the mechanisms of heat transfer, first.

Conduction
Conduction is mostly associated with heat transfer in solids. An example is when one end of a metal rod is heated, the heat is conducted to the other end. However, heat can also move through gases via conduction when the hotter and faster moving molecules collide with the colder slower moving ones. Solid materials have intrinsic thermal conductivity properties dependent on their atomic structures. Metals for example are good conductors whereas glass and other silica based materials are poor conductors. Smaller gas molecules such as hydrogen are better conductors than larger ones such as oxygen or nitrogen.

Convection
Convective heat transfer is only found in fluids. It is based on the principle that as a fluid heats it expands as its density is reduced. In the case of a gas such as air this will cause the warm air to rise. A practical application is a hot air balloon.

Radiation
Radiation is the transfer of energy by electromagnetic waves and is the mechanism by which the sun heats the earth. A body’s ability to both emit and absorb radiation is determined by its atomic structure.

Introduction
Vacuum insulation panel technology has existed for many years but only recently has it become commercially viable. This is mainly due to the development of lower cost, higher performing materials such as VACUPOR®, Porextherm’s proprietary microporous material based core.

Traditionally Vacuum Insulation Panels (VIPs) have been seen as a tool to increase energy efficiency in various applications. However, because of their performance and design flexibility they provide many more valuable application opportunities. These include increased volume in commercial and domestic refrigerators, increased shipping times for temperature controlled transportation systems, and reduced package size and weight for insulated shipping containers. Even applications in the building and construction sector are becoming more and more important, due to rising requirements to fulfill energy standards. Major competitive advantages can therefore be achieved by incorporating panels in the design of your products and systems. Porextherm® has an outstanding experience in serving customers with insulating material technologies and design capabilities.
Vacuum Technology

Vacuum technology can be used to inhibit all three heat transfer mechanisms. The “ultimate” example of vacuum insulation is the Dewar’s Flask, commonly known as a “Thermos bottle”. In a Dewar’s Flask the space between the dual walls of a cylinder is completely (99.999999%) evacuated. With virtually no molecules of gas available heat transfer by conduction and convection are almost eliminated and therefore thermal conductivities are extremely low – 0.00576 W/mK (R 250) or better.

Nevertheless, it is mechanically difficult to support such a pressure differential between the outside and inside of the flask. This certainly limits the structural configurations and the choice of materials for fabrication. Additionally, since even a few molecules of gas will destroy its insulation value, the cylinder walls must be absolutely impermeable to gas and moisture. Also because radiation travels best through a vacuum where there is nothing to hinder its path the wall materials are limited to either specially treated glass or metal, both have a tendency to conduct considerable amounts of heat at areas where the walls are joined together.

Comparison of thermal conductivity values between VACUPOR® and alternative insulation products

<table>
<thead>
<tr>
<th></th>
<th>R-Value (ft²·hr·°F/BTU·in)</th>
<th>Thermal Conductivity (mW/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VACUPOR® VIP® 1 mbar or 0.75 torr</td>
<td>30</td>
<td>4.8</td>
</tr>
<tr>
<td>Closed cell Polyurethane</td>
<td>4.1 – 7.6</td>
<td>19 – 35</td>
</tr>
<tr>
<td>Expandable Polystyrene (EPS)</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>Fiberglass batting</td>
<td>4</td>
<td>36</td>
</tr>
</tbody>
</table>

What are Vacuum Insulation Panels?

Vacuum insulation panels, or VIPs, consist of a filler material called a “core” that is encapsulated in a barrier film. The encapsulated system is then evacuated to a vacuum between 0.001 and 1 torr (0.001 and 1.5 mbar) and sealed thereafter. The core material serves three main purposes:

First, the core supports the panel walls. Atmospheric pressure exerts 14.5psi (pound per square inch) of pressure on the evacuated panel. This means that 2,000 lbs force are acting on a one square foot panel.

Second, the core material also inhibits the movement of the remaining gas molecules. The smaller the core pore size the more likely it is that the gas molecules will collide with the branched network of the filler material rather than each other. This essentially traps the molecules and any heat that is conducted to the solid core material is required to pass through a tortuous branch network where it is mostly dissipated. Porextherm’s® VACUPOR® core that is microporous material based has the smallest pore size and hence best insulating performance of any filler material.

Third, the core materials provide a barrier against heat transfer by radiation and often include special opacifying materials that scatter or absorb infrared radiation. A comparison between VACUPOR® vacuum panels and conventional insulation materials shows their significant superior performance.
Vacuum insulation panel technology

Vacuum insulation panels – performance and lifetime

The performance and life expectancy of a vacuum insulation panel is determined by a number of factors.

Following the major influencing criteria:

1. Properties of the core material
2. The initial vacuum level of the panel
3. The permeation rate of the membrane film and seals
4. The quantity and effectiveness of the getter and desiccant
5. Outgassing of the core material and film
6. The size and thickness of the panel
7. Conditions of use

Properties of the core materials

Current commercial VIP materials include polystyrene and polyurethane foams, precipitated silica and fumed silica. All vacuum insulation panels rely on high vacuum to provide their low thermal conductivity values. Nevertheless, fumed silica outperform any core type, even at higher pressure levels. As the level of vacuum in the envelope decreases the thermal conductivity rises. Still the relationship between internal pressure rise and increasing thermal conductivity varies tremendously with different core materials.

The graph on the right side indicates the effect of rising internal pressure on Porextherm® VACUPOR®-based VIPs in comparison to panels made from other core materials. Note that while all materials offer comparable performance at the highest evacuation levels, there are significant differences between them with only slight increases in internal pressure. Deterioration in performance is most pronounced with foams that can limit their use in many cases to shorter lifetime applications (<5 years).

Initial Vacuum Level

VIPs do not maintain a "perfect vacuum". Porextherm’s® VACUPOR® panels are evacuated to 1.13 torr (1.5 mbar) whereas other core materials are initially evacuated to an internal pressure of about 0.05 torr (0.067 mbar).

Creating vacuum levels lower than 1 torr would add significantly to the production cost and, in most cases, do not result in a higher insulation values. Panels that start out with a higher internal pressure will have a proportionately shorter effective lifetime than will an, otherwise identical, panel that is more thoroughly evacuated. Highest quality in the evacuation as well as in the sealing process is therefore most important.

Figure 1: Effect of pressure rise on thermal conductivity.
Membrane and seal permeation rates

The membrane film is the material that forms the walls of the VIP. All membrane films in use today permit some molecules of gas and moisture to pass through over time. The amount of permeation through a particular membrane film will depend on the material of its construction and the resistance of this material to degradation during handling in the production process. Some films contain of a very thin metal film (usually aluminum) which is reinforced by laminating a plastic film to each side. These films can have excellent barrier properties but can conduct significant heat around the edges. These “edge effects” can significantly reduce the effective performance of a VIP (for a more detailed analysis refer to “Thermal Edge Effects”, page 14 following). In order to reduce the unwanted “Thermal Edge Effects” to a minimum, some films are based on a thin film deposition technique which builds the metal layer even thinner. There are many films commercially available today and their properties and advice on selection are covered more fully in chapter two “Barrier Material selection”, page 9 following. The membrane films are sealed at the edges to form an envelope for the core material. A thin layer of low temperature plastic is laminated to the inside of the film so than it can be sealed using heat and pressure. These layers of heat-sealing plastic do not have the same resistance to gas and moisture permeation as does the rest of the film. To minimize the negative impact of permeation of the sealing layer, manufacturers use as thin a film layer as possible combined with a wide seal lip.

Getters and Desiccants

Getters are chemicals that absorb gases; desiccants are chemicals that absorb moisture. Getters and desiccants are used to extend the life of VIPs by absorbing unwanted gases and moisture that promote heat transfer within the evacuated space. To be effective, the getters and desiccants must be carefully matched to the kind and quantity of gas/moisture they will be expected to absorb. Besides that getters and desiccants must also be capable of effectively absorbing and holding the gases and moisture at the low pressures inside the VIP. It is, therefore, important that the quantity and type used be selected in accordance to the core material, membrane film and required life expectancy. Foam-based panels have no absorbent capacity at all. It is, therefore, necessary to add these chemicals into the VIP envelope. VACUPOR®-panels are natural desiccants itself. In addition getters are not required, even for long lifetimes (10 – 20 years) as long as a suitable barrier film is used. Getters can add significant cost to a panel and because of their heavy metal composition create major safety and environmental concerns.

Outgassing

Most materials release gases (outgas) when placed in a low pressure environment. The kind and quantity of gas released, as well as the length of time the outgassing will continue, varies from material to material. The released gases can contribute substantially to the rise in internal pressure (i.e. loss of vacuum) of a VIP. In some cases, the rate at which gas released from the core and membrane materials exceeds that at which it permeates through the membrane.

A few materials, such as Porextherm’s® VACUPOR® do not outgas at all, while other materials never stop outgassing. The core and membrane materials used by a particular manufacturer will determine what, if any, impact outgassing will have on the life of their product.

Size and thickness

Gas molecules can enter through the barrier film and the sealant material that bonds the film plies together. The larger the VIP the greater the film surface area vs. seal area and the smaller the VIP the greater the seal area vs. film surface area. Therefore, selecting a suitable barrier material requires that both the barrier film and sealant properties are appropriate for the type and size of panel. Thickness has a much greater effect on panel performance. Halving the thickness of a panel will halve the lifetime of a panel because the surface and seal areas remain almost constant whereas the insulation volume is halved. So although the transfer rates through the seal and barrier will be almost the same the gas pressure will be doubled because of the smaller volume.
Operating conditions

Operating conditions are important for both usability and lifetime. Usability refers to a panel's suitability for a given operating environment. Foams being plastics have a limited temperature range over which they can be used. Outside of this range shrinkage and deformation occur which can render a panel practically useless. For example the upper limit for polystyrene foams is 88 °C (190 °F) which rules out their use in applications such as hot water heaters and hot food delivery systems. Porextherm's® VACUPOR® core material can be used at temperatures up to 950 °C (1742 °F) with appropriate barrier films like e.g. stainless steel envelope*.

Operating conditions effect lifetime because the transfer rates of water vapor and gases through the barrier film and seals change with temperature. Higher temperatures promote increased transfer rates and lower temperatures slow down molecular movement. In addition, the higher the concentration of a gas surrounding the panel the higher will be its concentration in the panel and consequently the greater it's effect on heat transfer. In general the smaller the gas molecule the faster it will penetrate into the panel and greater will be its effect on thermal conductivity. So for example encasing a panel in polyurethane foam, the preferred method of application in refrigerators helps to prolong panel life because the heavy gas molecule of the foam blowing agent take longer to penetrate into the panel and when inside are not as good conductors of heat as nitrogen or oxygen because of their larger molecular sizes. Similarly for water vapor; the higher the humidity of the air around the panel the faster the transfer into the panel and the higher the final water concentration in the panel when equilibrium is reached.

Summary

Vacuum Insulation panels are an established technology in a number of applications including temperature controlled transportation, domestic and commercial refrigeration as well as construction insulation. Preferably, they be applied in any system where extra volume, better temperature control, longer shipping times, reduced shipping volume and weight or increased energy efficiency are desired. VIPs made from VACUPOR® can be supplied in many different shapes (flat, curved, round) thus enhancing their design flexibility. However, panels are usually not a “drop-in” solution and may require some redesign of your system to achieve the maximum benefits. Porextherm® has extensive experience and technical resources available to help find the optimum use of panels in your application.

* Porextherm does not offer stainless steel envelopes. On request, we can name you a source of supply.
Introduction

The lifetime and performance of vacuum insulation panels (VIP’s) depends upon the ability of the outer barrier or envelope material to prevent gases from penetrating into the panel during the panel’s operating lifetime. Low pressures are desirable for improved thermal performance because when the mean free path (the average distance a molecule will travel before hitting another molecule) of the gas approaches the pore size of the VIP insert, “gas phase thermal conduction” is greatly reduced. Therefore, having very small and uniform pores in the VIP insert is desirable since that allows operation at moderate vacuum levels. The “pore size effect” on the vacuum level required to eliminate gas phase conduction for various fillers is shown in Figure 1. For an insert such as an “open cell foam”, which has pores in the 10 to 100 micron size range, vacuum levels of 0.01 to 1 mbar are required to achieve good thermal performance. In contrast, VACUPOR® has pores in the 10 to 100 nanometer range (one thousand times smaller than foams) which means that only very moderate vacuum level are required. In fact, because of VACUPOR’S® small pores, even the thermal performance at ambient pressure is superior leading to significantly improved performance compared to other inserts if the barrier ever fails completely.

Although the VIP inserts shown above require different vacuum levels to operate, they all require a barrier to minimize the permeation of gases into the panel for it’s application lifetime. These gases may be atmospheric such as nitrogen, oxygen and water vapor or they may be application specific such as cyclopentanes, carbon dioxide and/or HCFC’s (when the VIP is encased in foam). The major issue in the selection of the appropriate barrier material(s) for a particular application is the compromise between the permeability of the barrier material(s) and the cost and thermal edge performance effects associated with the particular barrier.

Thermal edge effects (also known as thermal shunting or thermal short-circuiting) arise because the thermal performance of the highly porous insert is very high as compared to the dense barrier material. As a result, the effective thermal performance of a vacuum panel is always lower than the value measured at the centre of the panel. The magnitude of this difference depends upon the insert’s intrinsic thermal performance, the barrier thickness and composition, the boundary conditions around the VIP and most importantly, the VIP size.

In general, thermal edge effects are negligible for plastic and metallized plastic barriers and are quite significant when metal foil barriers are used. The effect of barrier material and VIP geometry are discussed more completely further on.
Properties of barrier materials

In general, barrier materials for vacuum insulation panels can be selected from either plastics, metallized plastics (for example, produced by vapor depositions of metals such as aluminum), metal foil/plastic composites produced by lamination, or welded metal foils. In most cases the barrier film structure is typically multilayer produced by lamination in order to impart a range of functionality to the film e.g. water and gas permeability, heat sealing, mechanical properties, etc. For barriers using metal foil, aluminum foil is the metal of choice because of its ductility, availability and cost. However, aluminum has a very high thermal conductivity which is why it is also the material of choice for cooling fins on electronics, etc. In fact, the thermal conductivity of aluminum is approximately 1,000 times greater than that of common plastics used in barriers and 20,000 to 100,000 times greater than that of typical VIP filler materials. Therefore, from a thermal edge effects viewpoint, the use of plastics or metallized plastics is strongly preferred as compared to metal foils.

Water vapor transport rates and Oxygen transport rates

For barrier materials, manufacturers typically report two properties related to how fast gases and vapors will permeate through the barrier. The first is the Water Vapor Transport Rate (WVTR) which has units of grams per square meter per day (in the U.S., grams per 100 square inches per day). From the known surface area and internal volume as well as accounting for any water adsorption by the VIP insert, the water partial pressure and amount of water in the VIP as a function of service life can be calculated for a barrier with a given WVTR. As with all barrier properties, the manufacturer’s WVTR represent a best case that can only be approached in a VIP. The second property often quoted by the barrier producer is the oxygen permeability or Oxygen Transport Rate (OTR) in units of cm3/m2 per day per atm (or cm3/100 in2 per day per atm in the U.S.). Although oxygen only represents ~21% of the atmosphere, the oxygen permeability is reported because of its effect on food degradation and the fact that oxygen transport through many plastics is quite high.

For vacuum panels, the permeation of nitrogen is also of major concern since it represents the most plentiful atmospheric gas. For many plastics, the nitrogen permeability is four to five times lower than that of oxygen but this is offset by the pressure driving force which is four times larger than that of oxygen because of the higher concentration. For VIP applications in which the panel will be surrounded by gases and vapors other than atmospheric gases, the permeability of the barrier for those gases must be measured for accurate lifetime predictions.

For simple, single component plastics ranging from polyethylene to nylon to PVDC, the WVTR typically has values ranging from 1 to 300 g/m² · day and the OTR ranges from 0.3 to 4,000 cm³/m² · day · atm. For a plastic, the properties of being a good barrier for both water and for oxygen do not normally coincide. This is the reason why composite films are normally employed. In addition to layers for water vapor and oxygen permeability, layers are often added to heat sealing and as an adhesive between layers. Depending upon the thickness and composition of a laminated structure, WVTR values of 0.02 to 0.2 g/m² · day and OTR of 0.05 to 0.5 cm³/m² · day · atm. are achievable but can be quite expensive. For lower values, one can use either metallized films, which have one or more thin layers of vapor-deposited metals such as aluminum vapor or laminates which employ thin aluminum foils. The advantages of metallized films are minimal “Thermal Edge Effects”, safer processing and lower cost but they typically do not achieve as low a permeability as foils. Metallized films offer WVTR values in the 0.01 to 0.5 g/m² · day and OTR values of 0.01 to 0.5 cm³/m² · day · atm. In contrast, laminates containing aluminum foils have lower permeability but suffer from significant thermal edge effects and high cost.
Model for gas permeability

Below are the predicted pressure rises over a 30 year lifetime in a 25 mm (1" thick) VACUPOR® VIP using barrier materials with a range of OTR values. The calculations include oxygen, nitrogen and water vapor permeation. The calculations assume zero initial pressure and any residual pressure actually in the panel should simply be added to the calculated pressure. For thinner panels, the pressure rise occurs faster. For a panel which is 12.5 mm thick, the time required to reach the same pressure will be 1/2. These calculations assume that the barriers have been correctly sealed. Since the change in thermal performance with pressure is different for various VIP inserts (see Figure 1), the effect of the pressure change during the panel’s lifetime will be quite different.

Using the pressure versus lifetime results for the K = 0.1 barrier of Figure 2, the thermal conductivity as a function of lifetime can be calculated. This is illustrated in Figure 3 for VACUPOR® and an open cell polystyrene. Desiccants or getters are not used for either insert. In general, foams require barriers with permeability (OTR and WVTR) which is approximately 100 times lower than for VACUPOR® because of the more stringent vacuum requirements associated with the larger pore sizes of foams. This is difficult to achieve without employing foil-based laminates with their associated thermal edge effects and high cost.

![Figure 2: Pressure rise in a 25 mm thick VIP as a function of OTR in cm³/m² · day · atm. For illustration, the WVTR (in g/m² · day) is taken as the same value as the OTR and the nitrogen permeability is taken as 20% of the OTR.](image1)

![Figure 3: Thermal performance of various VIP insert materials at ambient temperature measured under a 1 atmosphere load as a function of product life for a barrier material with an OTR of 0.1 cm³/m² · day · atm, WVTR of 0.1 g/m² · day and nitrogen permeability of 0.02 cm³/m² · day · atm.](image2)
Barrier material selection

**Water vapor transport**

The transport of water vapor through barrier materials and into VIP’s is discussed separately from the gas permeation above for three main reasons.

- For insulation applications near ambient temperature or below, water is different from other atmospheric gases because the total pressure that it can be achieve during the lifetime of the panel is limited by the equilibrium vapor pressure.

- The second reason is that because of its low molecular weight and unique chemical structure, barrier materials which are excellent barriers for gases such as oxygen and nitrogen may not be good barriers for water vapor and vice-versa.

- Finally, some VIP inserts such as VACUPOR® and precipitated silica can adsorb large quantities of water which mitigate the pressure rise associated with a given quantity of water permeating into the VIP.

This effect is indicated in Figure 4 which illustrates the pressure in the panel after different quantities of water have permeated into the panel. These results are for ambient temperature which means that the water vapor pressure would never exceed ~28mbar. The pressure in the opencell foam rises rapidly to the equilibrium water vapor pressure. Since they can only tolerate pressures of 1mbar before a large degradation in performance is observed, water sensitivity is a major problem. In order to ban this problem, barriers with very low water permeation rates must be utilized. Also, expensive desiccants and getters are often added to foam-based panels to keep the water partial pressure low.

However, since the rate of water transport across the barrier depends upon the relative humidity inside and outside the panel, if the pressure is maintained low in the panel, the water transport rate is higher than if the water pressure inside is close to ambient. Therefore, getters and desiccants which strive to maintain the very low partial pressures necessary in foam panels actually serve to promote faster water transport.

Also, depending upon the nature of the getters/desiccants employed, they can involve significant recycling and safety problems.

In contrast to foams, VACUPOR® and precipitated silica vacuum panels do not suffer from this water problem since they can operate at higher pressures (on the same order as the saturation pressure for VACUPOR® in many applications) and contain a large amount of inherent water adsorption capacity.

![Figure 4: Thermal performance of various VIP inserts at ambient temperature measured under a 1 atmosphere load as a function of gas pressure.](image-url)
In general, the loss in thermal performance with moisture uptake near ambient temperature is roughly proportional to the moisture content (i.e., 0.1 grams of water per gram of VACUPOR® corresponds to a 10% decline in thermal performance).

Figure 5 shows the predicted amount of water which will enter a 25 mm thick panel if surrounded by a 100% humidity atmosphere. If the panel is one half this thickness, the time required to achieve a given moisture content would be one-half of the designated value.

This implies that the water vapor transport rate (WVTR) of the barrier film for VACUPOR®-based inserts needs to be only on the order of 0.1 grams/m²·day for product lifetimes of several years and 0.01 grams/m²·day for lifetimes well in excess of 10 years. These values for WVTR are easily obtained with certain relatively inexpensive, metallized barrier films which are commercially available.

**Figure 5:** Water uptake for 25mm thick VACUPOR®-based vacuum panels in a 100% humidity atmosphere for barrier films of various WVTR values.
Thermal edge effects

Introduction

The lifetime and performance of Vacuum Insulation Panels (VIP’s) depends upon the ability of the barrier film or envelope material to maintain a defined vacuum level during its lifetime. The major criteria in the selection of the appropriate barrier material for a particular VIP application is the compromise between the permeability of the barrier material itself, its cost and its thermal edge performance effects. Thermal edge effects result from a relatively high thermal transport region in the barrier material around the vacuum panel. This occurs to some extent with any barrier composition and thickness. The effective thermal performance of a vacuum panel is always lower than the value measured at the center of the panel. The “center-of-panel” value is the thermal performance value that is usually reported by panel manufacturers/suppliers since it is much easier to measure than the effective thermal conductivity. However, the effective conductivity is what describes the actual performance of the VIP in the final application.

“Thermal Edge Effects”, also known as thermal shunting or thermal short-circuiting, arise because the thermal performance of the highly porous vacuum panel inserts are very high as compared to the dense barrier materials.

This thermal edge effect is schematically illustrated below. The graph indicates the relative magnitude of the heat or energy flow by size of the flux arrows. Thus the flux at the panel’s center point is the lowest which implies that the VIP thermal performance is the highest at the center.

The effective thermal conductivity or performance requires consideration of the heat flux throughout the entire VIP surface. In other words, the intrinsic thermal performance depends on the VIP insert, the thickness and composition of the barrier, the boundary conditions around the VIP and most importantly, the size of the VIP.

Influence of barrier materials

In general, barrier materials for vacuum insulation panels can be selected from either plastics, metallized plastics (for example, produced by vapor depositions of metals such as aluminum), metal foil/plastic composites produced by lamination, or welded metal foils. In most cases the barrier film structure is typically multilayer produced by lamination in order to impart a range of functionality (water and gas permeability, heat sealing, mechanical properties, etc.) to the film. For barriers using metal foil, aluminum foil is the metal of choice because of its ductility, availability, and cost. However, aluminum has very high thermal conductivity properties. In fact, the thermal conductivity of aluminum is approximately 1,000 times greater than that of common plastics used in barriers and 20,000 to 100,000 times greater than that of typical VIP filler materials.
Modeling of thermal edge effects

For a square VIP of thickness equal to 25mm and of varying lengths, the effective thermal conductivity can be estimated as a function of VIP size by assuming a boundary condition model and fixing the VIP inner core thermal conductivity. The figure beside shows the effective thermal conductivity as a function of the side length of the square VIP for the case when the inner core has a thermal conductivity of 0.0036 W/mK (3.6 mW/mK) or R/inch equal to 40. Calculations have been performed for four different barrier material using typical thickness for the different layers. The 50 micron plastic exhibits negligible effects for all practical VIP sizes. However, for some VIP inserts/fillers which require extreme vacuum levels, plastic only barrier materials offer inadequate barrier performance. Using a relatively large amount of aluminum metallization on the plastic, edge effects still disappear for panels larger than 150 mm (6.0 inch) on a side. Depending upon the desired VIP lifetime, the critical pressure of the VIP filler material and the number and type of metallization layers, metallized films may not provide sufficient barrier performance. However, for VIP inserts which operate at higher pressure levels, relatively inexpensive metallized barriers offer more than adequate VIP lifetimes. If better barrier performance is required for materials which must be maintained below several mbar pressure for the lifetime of the panel, than foils are used.

The thinnest available foil-based barrier has a foil thickness of approximately 7.5 microns. As shown in the figure, for a 300 mm · 300 mm · 25 mm (11.81" · 11.81 · 1") VIP using that type of barrier, the effective performance would only be 1/3 of that if there were no edge effects.

For a 500 mm · 500 mm · 25 mm (19.68" · 19.68 · 1") VIP, the performance would only be 1/2 of the performance with no edge effects. Due to the high cost of producing these very thin aluminum foil based laminates with a minimum of pinholes, thicker foils can be used which are actually cheaper.

25 microns is typically taken as the thinnest foil which has no pinholes. However, as shown below, the edge effects associated with these thicker barriers practically precludes their use. Based on these results, it is clear that unless the panels being used are extremely large, the thermal performance of VIP's can only offer dramatic improvement over conventional insulation in the end-use application if the plastic or metallized plastic barriers are used. The quantitative results presented above would be slightly different for different boundary conditions or for VIP insert materials with different intrinsic thermal conductivity. However, the same general trends would be observed. Therefore, when selecting a VIP insert material and the barrier material, it is important to balance the effects of the barrier on thermal performance, on VIP lifetime, and on overall cost of the VIP.