Kevothermal Technology Overview

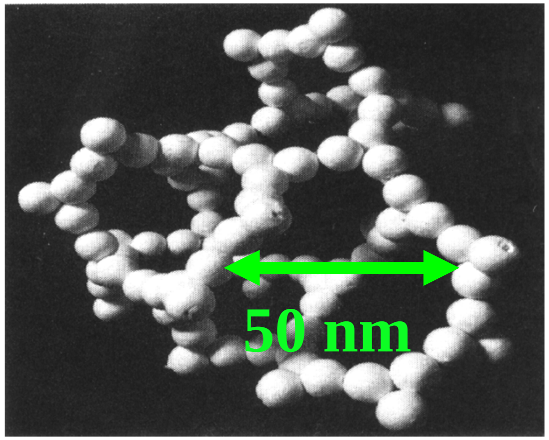
Introduction:

When insulation is enclosed and subjected to a vacuum, the thermal performance of the insulation improves. The magnitude of this improvement depends upon:

1) the operating temperature and temperature range
2) the vacuum level achieved
3) the filler gas
4) the properties of the insulation such as the pore size distribution, density, opacification, etc..

Low pressures are desirable for improved 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 insulation, gas phase thermal conduction is greatly reduced.

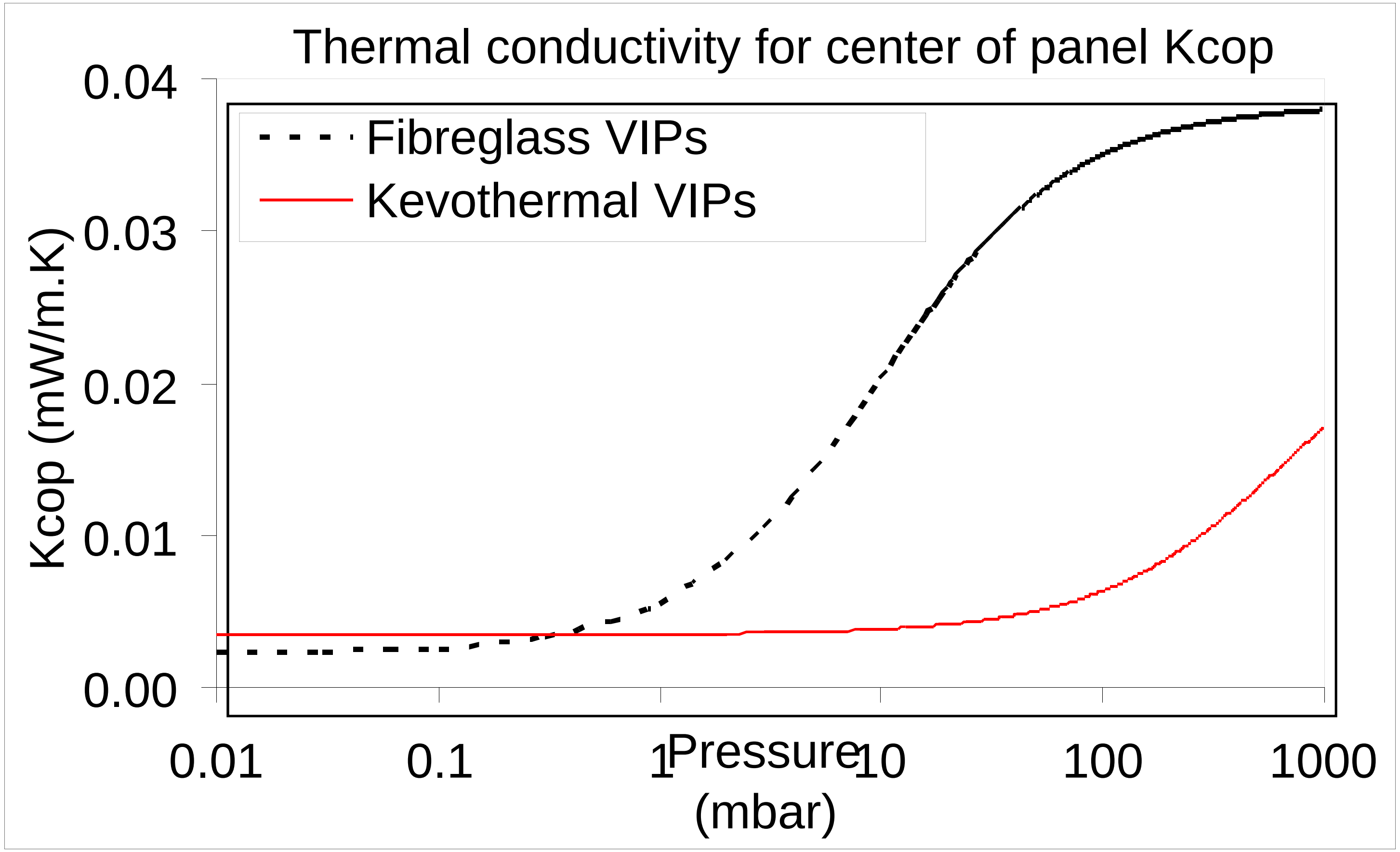
Depending upon the insert material, the relative increase in performance with vacuum will change. Having very small and uniform pores in the VIP insert is desirable since that allows operation at moderate vacuum levels. This pore size effect is shown in the following slide. For inserts such as open cell foams and fiberglass, which have pores in the 10 to 100 micron range, vacuum levels of *0.01 to 1 mbar* are required for good performance. In contrast, the Kevothermal core material has pores in the 50 nanometer range (approximately one thousand times smaller than foams and fiberglass) which means that only moderate vacuum levels are required.



Because the vacuum level of all VIPs will degrade over time, this directly affects the lifetime performance of the VIP.

Thermal performance vs. Pressure

Comparison of the pressure dependence on the Thermal Conductivity of the Center of Panel (K_{cop}) for metalized SiO2 VIPs compared to 6 um Al foil fiberglass VIPs



Barrier Film Performance

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.

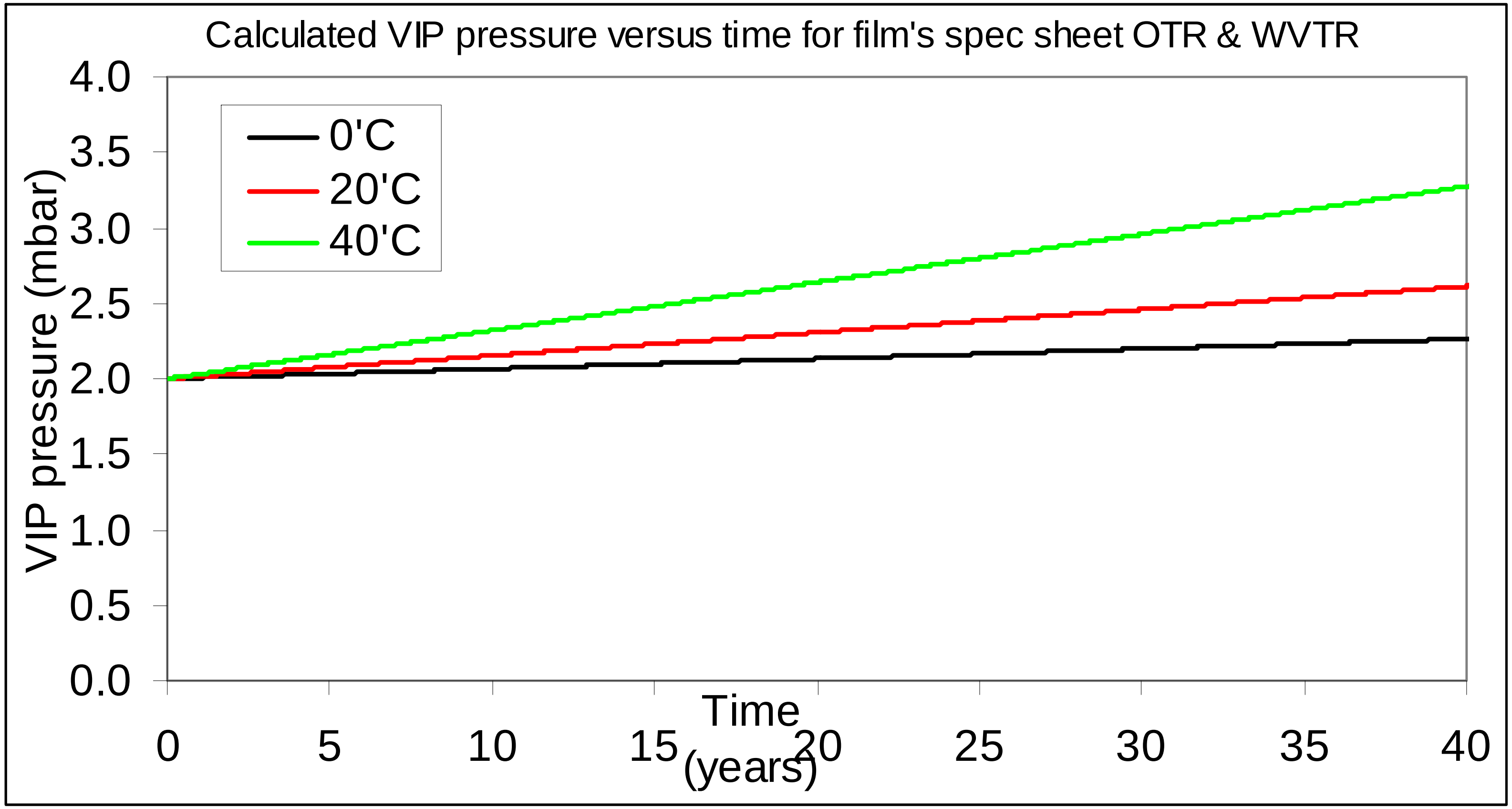
These gases may be atmospheric such as nitrogen, oxygen and water vapor or they may be application specific such as cyclopentanes, carbon dioxide and/or HCFC's (when the VIP is encased in foam). The major issue in the selection of the appropriate barrier material(s) for a particular application is the compromise between the permeability of the barrier material(s) and the cost and thermal edge performance effects associated with the particular barrier.

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/m2per day per atm (or cm3/100in2per 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.

The graph on the following slide models VIP internal pressure as a function of time based upon the WVTR and OTR of Kevothermal's barrier film.

Internal Pressure vs. Time

Kevothermal VIP internal pressure as a function of time at varying temperatures



Edge Effects

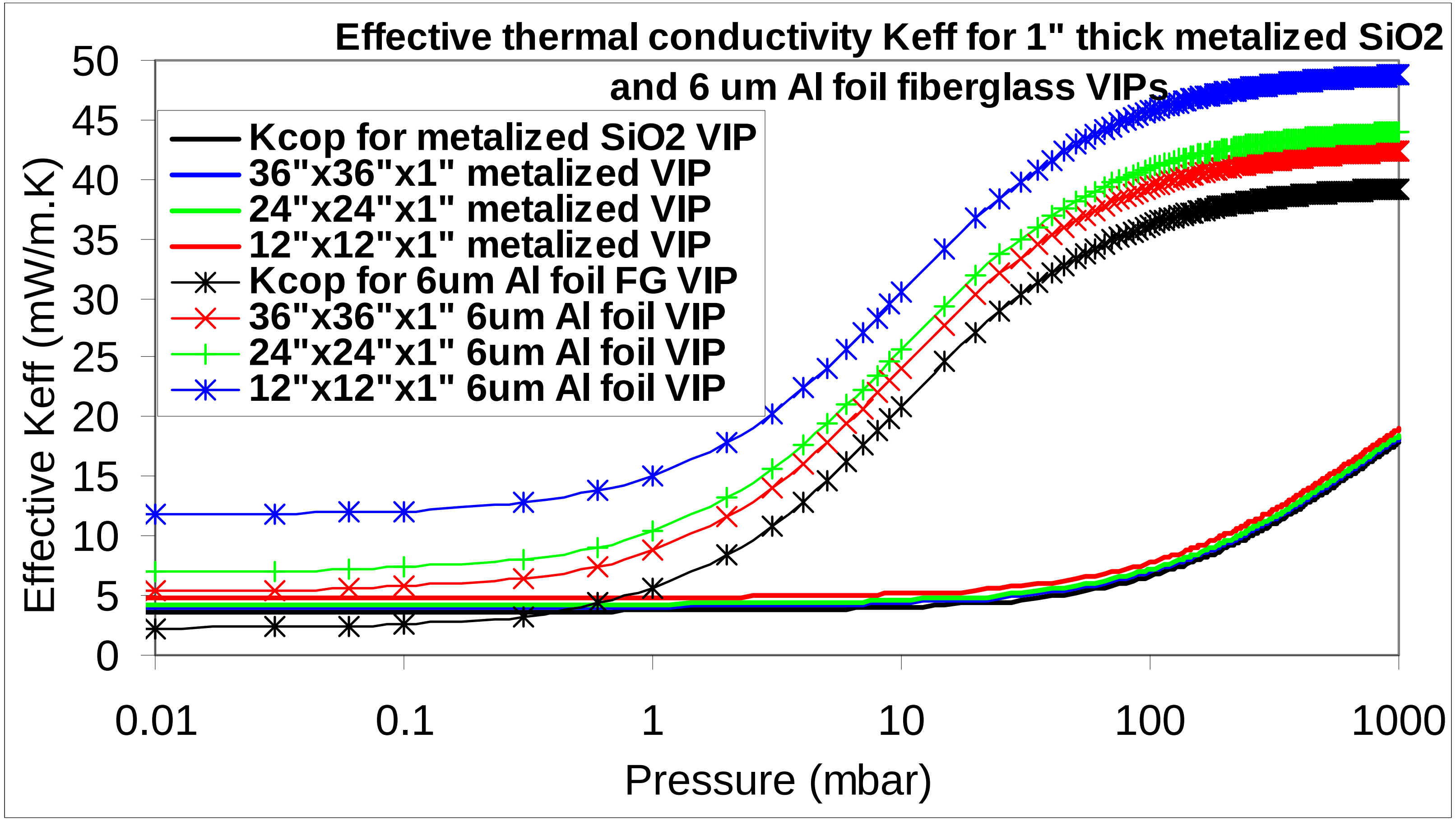
In general, barrier materials for vacuum insulation panels can be selected from either plastics, metalized plastics (for example, produced by vapor depositions of metals such as aluminum), metal foil/plastic composites produced by lamination, or welded metal foils. In most cases the barrier film structure 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 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 <u>1,000 times greater</u> than that of common plastics used in barriers and <u>20,000 to 100,000 times greater than that of typical VIP filler materials</u>. Therefore, from a thermal edge effects viewpoint, the use of plastics or metalized plastics is strongly preferred as compared to metal foils.

However, due to the rapid deterioration in thermal performance that occurs in fiberglass or open cell foam VIPs as the internal pressure increases, manufacturers of these panels often default to foils to maintain thermal performance.

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.

The following slides show the effect of these thermal bridges on the overall performance of a VIP.

Edge Effects



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Edge Effects

Edge effects as a function of VIP size