Performance of VIP Laminates under High-Temperature Conditions

- Gas Permeation Measurement at High Temperatures

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Table of Contents

Performance of VIP Laminates under High-Temperature Conditions - Gas Permeation Measurement at High-Temperatures

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Goal:

To evaluate the gas barrier performance of different Vacuum Insulation Panel (VIP) laminates at elevated temperatures (80°C – 150°C).

Test Procedure:

1. VIP panels were prepared with different envelopes based on Aluminum foil laminates, metallized Aluminum laminates, or Hybrid (one side Al foil and the other metallized) envelopes. The inspected laminates used were:

    i. V085HB0 - metallized layers of EVOH and PET with HDPE sealing layer.

    ii. V085HB1 - metallized layers of EVOH and PET with LDPE sealing layer.

    iii. V085HB2 - metallized layers of EVOH and PET with PP sealing layer.

    iv. V08621B - metallized layers of PET with LDPE sealing layer.

    v. V08627 - metallized layers of PET with HDPE sealing layer.

    vi. V07941P – Al foil based laminate with LDPE sealing layer.

    vii. V07911P – Al foil based laminate with HDPE sealing layer.

    viii. V085HB0 + V07911P – Hybrid (MEVOH+MPET) with HDPE sealing layer.

    ix. V085HB1 + V07941P – Hybrid (MEVOH+MPET) with LDPE sealing layer.

    x. V08627 +V07911P– Hybrid (MPET) with HDPE sealing layer.

Panel size: 300mm x 300mm, in thicknesses varying from 7-10 mm.

2. Panels of each type were stored at 80°C, 100°C, 120°C, and 150°C.

3. The thermal conductivity of the panels was measured at intervals of 3-7 days in the first month and once again after two months.

4. The permeability of each envelope was calculated.

5. Permeability results were fitted to the Arrhenius equation.

Results:

The dependence of thermal conductivity on the pressure of fiberglass core material was determined prior to panel preparation by a proprietary method developed by Avery Dennison Hanita. Here, core material analysis was conducted by the simultaneous measurement of pressure and thermal conductivity (see figures (a) and (b) below).

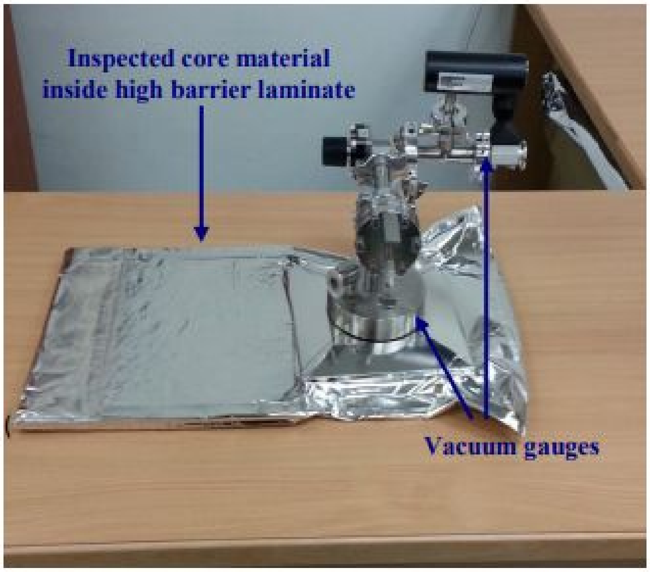


Figure 1 (a) Sample for core material characterization

Figure 1(b) Sample inside thermal conductivity measurement device (LaserComp FOX314)

The first measurement of thermal conductivity was made while the whole system was evacuated by a turbo-molecular vacuum pump. This ensured that the pressure inside the envelope was kept at a low level of 1×10-3 mbar, to determine the λ_0 of the inspected glass fiber.

At the following measurements, a controlled amount of gas was injected into the envelope, and the thermal conductivity was measured after each gas injection. Finally, measurement results were fitted to the following equation, published by U.Heinemann ("Relationship between pore size and the gas pressure dependence of the gaseous thermal conductivity"):

$$\lambda(P)=\lambda_0+\frac{\lambda gas}{\left(1+\frac{P_{1/2}}{P}\right)}+\frac{\lambda coupl}{\left(1+\frac{P_{1/2}coupl}{P}\right)}$$

Where λ_0 is thermal conductivity at low pressure such as 1 x 10^{-2}mbar, λ_0 depends on the dimensional structure of the core material. ***λgas*** and ***λcoupl*** are the thermal conductivity of air $(25.5\frac{mW}{m\cdot K})$ and thermal conductivity due to coupling effects in the skeleton of the core material $(11\frac{mW}{m\cdot K})$ respectively. and $P_{1/2}coupl$ are specific pressures that depend on the pore size of the core material.

Analysis results are presented in Figure 2 below.

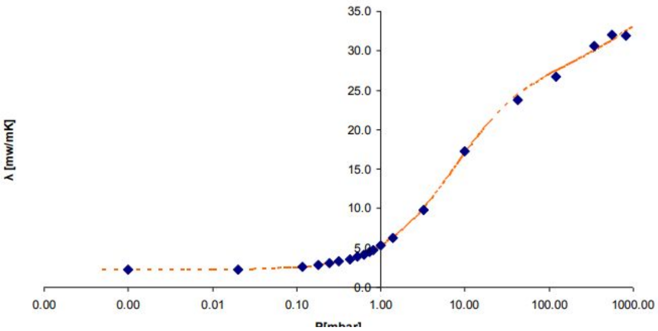


Figure 2 –Thermal conductivity as a function of Pressure

The blue dots describe measurement results, while the orange line is a plot of the equation above when

$\lambda_0[mW/mK]$	$\lambda gas[mW/mK]$	$P_{1/2}[mbar]$	$\lambda coupl[mW/mK]$	$P_{1/2\,coupl}[mbar]$
2	25.5	7	11	1000

* The values in the table gave the best fit to the measured results.

Calculation of Pressure

Knowing the above parameters of the core material used allows us to calculate the pressure inside the VIP panel, for each measured value of thermal conductivity.

The table and Figure 3 below present an example of the thermal conductivity measurements of V085HB0 (metallized layers of EVOH and PET with HDPE sealing layer) at 120°C.

Envelope Size		Duration[days]	λ [mw/ m ·k]	P [mbar]
Length [mm]	335	0	2.628	0.18
Width [mm]	335	1	Into 120°c	
Core size		9	6.693	1.58
Length [mm]	300	16	8.442	2.37
Width [mm]	300	24	10.3	3.38
		35	11.99	4.51
Thickness [mm]	7.15	62	15	7.28
A[m2]	V[cm3]		dp/dt [mbar/day]	Permeability [cc(stp)/year m2]
0.112225	643.5		1.06×10^{-1}	221.85

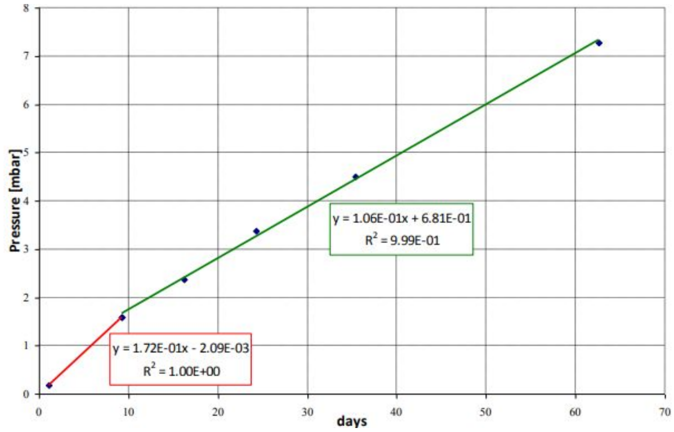


Figure 3: Thermal conductivity measurements of V085HB0 (metallized layers of EVOH and PET with HDPE sealing layer) at 120°C.

As seen in the graph above, there are two different pressure increase rates. The initial pressure increase (red line) is higher due outgassing effects, whilst the green line shows the permeability of a laminate without the effects of outgassing, calculated using a steady state pressure increase (green line). Steady state refers to the absence or negligible influence of outgassing phenomena on pressure increase inside the VIP.

Permeability in the VIP is the amount of gas that permeates through one cubic meter of panel over one year and is calculated using the following equation:

$$Per[cc(STP)/year\ m^2] = \frac{\partial P}{\partial t} \times \frac{V}{A}$$

Where:

$\frac{\partial P}{\partial t}$ is the pressure increase over one year at steady state, which calculated from thermal conductivity measurements

V is the volume of the panel – product of length , width and thickness of the core material inside VIP.

A is the area of the envelope - product of length and width of the VIP bag.

The pressure increase inside a VIP panel over one year at a specific temperature is obtained by dividing the permeability of the envelope at that specific temperature by the thickness of the panel. For example, if an envelope has a permeability of 2cc(STP)/year m^2 at 25°C and a panel thickness of 20mm, the pressure increase will be 0.1 mbar per year.

Figure 4 below shows the permeability of each envelope at different temperatures, as observed after one month in an ongoing test.

Temperature [°C]			80	100	120	150
Product			Permeability [cc(STP)/year m2]	Permeability [cc(STP)/year m2]	Permeability [cc(STP)/year m2]	Permeability [cc(STP)/year m2]
🟦	V085HB0	Metallized EVOH and PET with HDPE	31	84	222	736
🟦	V085HB1	Metallized EVOH and PET with LDPE	38	92	295	899
🟫	V085HB2	Metallized EVOH and PET with PP	54	106	284	769
⬛	V08621B	Metallized PET with LDPE	84	193	499	1492
🟪	V08627	Metallized PET with HDPE	72	173	372	1303
🟪	V07941P	Al foil based laminate with LDPE	24	54	159	488
🟥	V07911P	Al foil based laminate with HDPE	15	38	109	345
🟥	V085HB0 + V07911P	Hybrid (MEVOH+MPET) with HDPE	25	62	179	541
🟦	V085HB1 + V07941P	Hybrid (MEVOH+MPET) with LDPE	31	77	205	580
🟩	V08627 + V07911P	Hybrid (MPET) with HDPE	54	104	218	632

Figure 4: Permeability according to Temperature

From previous observation, we can assume that permeability values are not going to change significantly, so long as no catastrophic failure such as separation of laminate occurs. Figure 5 below presents Arrhenius fit of metallized VIP, whilst Figure 6 below presents Arrhenius fit of Al foil and Hybrid VIP.

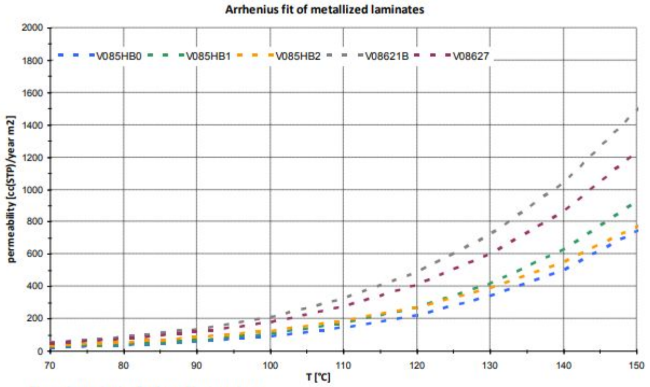


Figure 5 – Arrhenius fit of metallized envelope

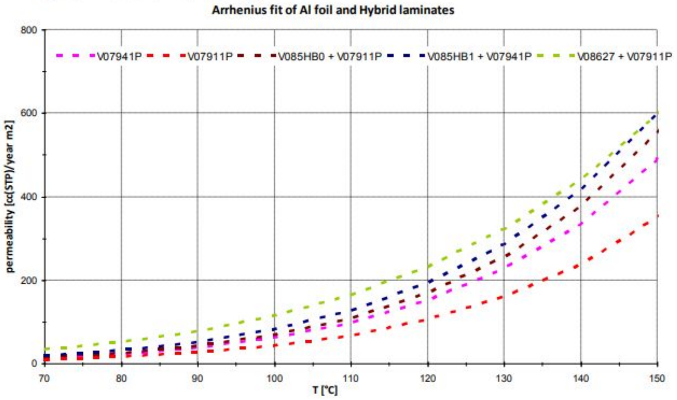


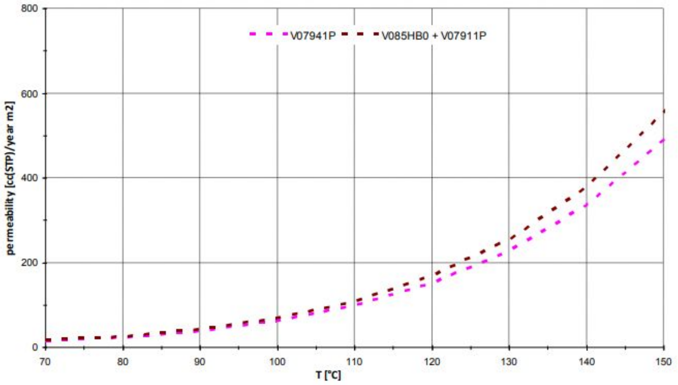
Figure 6: Arrhenius fit of Al foil and Hybrid envelope

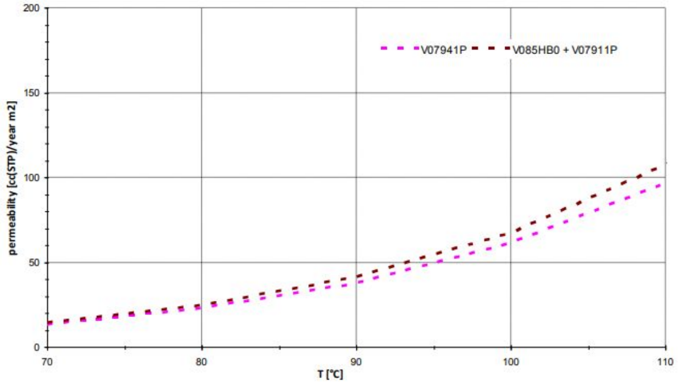
Conclusions:

1. All the laminates tested can withstand high-temperature conditions, keeping a certain level of vacuum. This enables the use of VIPs for high-temperature applications when the applications are limited to **long term with a short period of exposure to elevated temperature, or to short term with constant exposure to elevated temperature.** See an example shown in the Appendix.

2. V085HB0 + V07911P – Avery Dennison Hanita's Hybrid metallized EVOH with HDPE sealing layer delivers a similar level of gas barrier (see in the Appendix) to Al foil laminate with LDPE layer at high temperatures. In other words, providing **a foil-like barrier to gas - without the thermal bridge effect that affects the performance of foil based laminates.**

Appendix:





Estimation of VIP lifetime operating at high temperatures: Panel size – 500mm x 500mm x 20mm Pressure inside the panel immediately after evacuation – 5x10-^{2} mbar Thermal conductivity (effective – cop + tb) at the end of life – 12 mW/ mK (**λ** end of life).

1 st case: constant exposure to elevated temperature - hot side of the panel exposed to 100°C and cold side of the panel exposed to 30°C.

2nd case: temporary exposure to elevated temperature – 20% of the time the hot side of the panel is exposed to 0°C and the cold side of the panel is exposed to 40°C, the rest of the time the panel is surrounded by an air temperature of 25°C.

The table below shows the estimated lifetime of VIPs operating at high temperature:

	Fiber glass (λ_0=2mW/mK, $P_{0.5}$ = 7 mbar)		Fumed Silica (λ_0= 4mW/mK, $P_{0.5}$ = 700 mbar)	
	Years to reach λ end of life		Years to reach λ end of life	
Panel envelope	**1st case**	**2nd case**	**1st case**	**2nd case**
V085HB0	1.5	2.5	>15	>15
V07911P+V085HB0 Hybrid	1.5	3	>15	>15
V07911P	0.8	1.3	10	~15

The presented values are a rough estimation of VIP longevity and may vary with a change of core material, temperature, relative humidity, etc. When precise data is known, a more accurate calculation can be made by Avery Dennison Hanita.

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R&D - Ultra High Barrier Laminates
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