SERVICE LIFE PREDICTION FOR VACUUM INSULATION PANELS (VIP)

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ABSTRACT

VIPs in building envelopes offer a wide range of energy saving solutions and new design options, because space consuming conventional thermal insulation boards may be substituted by a thin VIP layer. On the other hand, quality requirements and testing procedures as well as design rules for building applications of this product aren't yet established. In particular ageing and thermal bridge effects of VIP have to be taken into account in a realistic way. In order to improve knowledge and increase confidence in VIP products, the Laboratory for Applied Physics in Building of the Swiss Federal Testing and Research Institute (EMPA) participates in Annex 39 "High Performance Thermal Insulation Systems (HiPTI)" of the International Energy Association IEA. First results of accelerated ageing and service life estimation are reported in the present contribution. Basic considerations with respect to thermal bridge effects and calculated examples are presented in another CISBAT paper [1].

ZUSAMMENFASSUNG

Vakuum-Isolationspaneele (VIP) eröffnen einen breiten Anwendungsbereich für energiesparende Konstruktionen und neue architektonische Lösungen, da dünne VIP-Schichten anstelle von voluminösen konventionellen Wärmedämmungen eingesetzt werden können. Qualitätsanforderungen, Testverfahren und Planungsgrundlagen für Bauanwendungen solcher Produkte sind jedoch noch nicht vorhanden. Insbesondere Alterungseffekte und Wärmebrücken sind genauer zu untersuchen, da VIPs in Bezug auf diese Fragestellungen nicht mit bisherigen Dämmstoffen vergleichbar sind. Mit diesen Schwerpunkten beteiligt sich die EMPA-Abteilung Bauphysik am Annex 39 "High Performance Thermal Insulation Systems (HiPTI)" der Internationalen Energieagentur IEA. Erste Resultate von beschleunigten Alterungsversuchen und Lebensdauerabschätzungen von VIP für den Baubereich werden im vorliegenden Beitrag beschrieben. Grundsätzliche Betrachtungen und berechnete Beispiele im Zusammenhang mit Wärmebrückeneffekten beim Einsatz von VIP im Bauteilen sind in einem weiteren CISBAT-Beitrag dokumentiert [1].

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INTRODUCTION

In the last few years a novel type of a thermal insulation board, the so-called "vacuum insulation panel" (VIP), has been developed for building envelope application. At present it is typically made of a micro-porous core structure which is evacuated and sealed in a thin, mostly gas tight envelope (Figure 1).

In most products appearing on the market fumed silica (SiO_2 agglomerates) is the main component of the core material. Compressed to about 200 kg/m^3 the pore size between the SiO_2 grains is well below the mean free path of gas molecules at an internal pressure below 1 mbar. Since the molecular collision rate is strongly reduced in this case, gaseous heat transfer becomes virtually negligible. Heat transfer is thus limited to solid conduction (about 3 mW/(m K)), and thermal radiation (less than 1 mW/(m K) by admixture of opacifier). Hence the total thermal conductivity of the evacuated SiO_2 core is about 4 mW/(m K). This is roughly a factor 8 lower than with conventional thermal insulation boards.

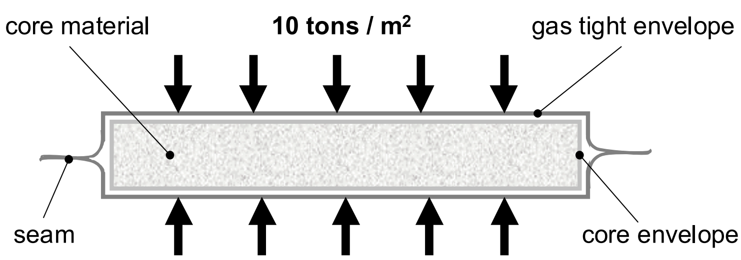

Fig. 1: Schematic cross section through a VIP (left), comparison of a conventional mineral wool insulation board and a VIP with equal thermal resistance (right).

The quality of the barrier is a key issue for the proper function of a VIP, especially for a long-term building application. Lowest permeation rates can be expected for "massive" metal layers with a thickness of several micrometers. Respective VIPs with polymer laminated aluminium foils are currently available. However, thermal measurements and numerical calculations at EMPA show that the edge heat flow through a metal foil envelope can be much larger than the heat flow through the VIP core itself [1]. With regard to durability the thermally welded PE seam still remains potential weak point of aluminium laminated VIP.

In order to reduce the thermal bridge problem, metallised polymer films are now widely used with VIP products for building application. To overcome the gas permeability problem newly developed laminated high barrier films include up to three metallic layers with a thickness in the range of 30 - 100 nm each. Although better performance compared to a standard metallised film can be expected, it is an open question if those barriers really achieve the stringent requirements to ensure a target VIP service life in the order of 25 to 50 years.

While VIP application is growing rapidly, testing procedures as well as service life prediction for VIP are not established up to know. Therefore, this is a major work area at EMPA along with other participants in the framework of Annex 39 "High Performance Thermal Insulation Systems (HiPTI)" of the International Energy Association IEA [2]. First results are reported in the following sections of the present paper. A second focus at EMPA is put on calculation and experimental validation of thermal properties of bare VIP and building components with built-in VIP (see CISBAT contribution [1]). More information on Swiss activities in the VIP field can be found on www.vip-bau.ch.

SERVICE LIFE OF VIP

Since the thermal conductivity of the SiO_2 core material is increased by about a factor 5 between low pressure (1 hPa) and standard atmospheric pressure, gas permeation through the VIP envelope is a critical ageing mechanism in regard to the service life of a VIP (Figure 2).

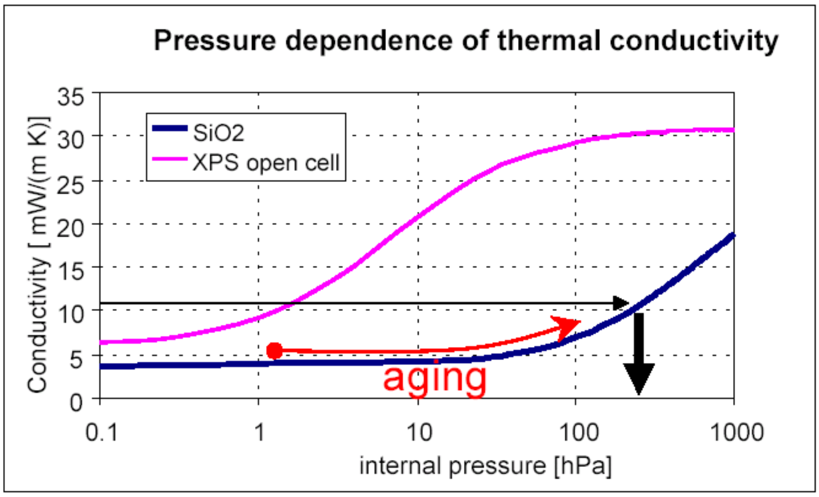

Fig. 2: Thermal conductivity of two core materials as a function of the gas pressure in the pores.

There are many possible failure modes, starting with "childhood" failure caused by imperfect production. This problem frequently appeared in the beginning of VIP production. Since then the "early failure" rate was clearly lowered on the basis of improved process and quality control. Another cause for sudden failure is of course mechanical damage of the delicate envelope during installation. Damage of panels during installation was present on several construction sites visited by EMPA. Therefore on-site installation of unprotected VIP cannot be recommended.

Normally, pressure increase in a VIP will take place due to "natural" permeation of atmospheric molecules through a more or less permeable barrier. There is no standardised end-of-life criterion for this "ageing" process yet. Based on the SiO_2 characteristics shown in Figure 2 a reasonable choice could be 100 to 200 hPa. Then, for a target service life of 50 years, a pressure increase rate between 2 and 4 hPa per year would be acceptable.

Looking at recent metallised polymer barrier films (MF) used for VIP, oxygen transmission rates OTR from 0.05 to as low as 0.0005 $STDcm^3/(m^2 day)$ at 23°C 50% r.H. are declared by manufacturers [3]. If the nitrogen transmission rate NTR is in the same order of magnitude (typical assumption is NTR ≈ OTR / 4), a pressure increase in the order of 0.01 to 1 hPa per year could be expected in a 1 m x 1 m x 0.02 m panel. However, this is too optimistic for several reasons:

i) A typically non-linear increase of the permeation rates at higher temperature and/or humidity will accelerate the pressure increase. The temperature dependence of a permeation rate for polymeric materials is often described in form of an Arrhenius acceleration factor:

$$P(T)/P(T_{ref}) = \exp\left(-\frac{E_a}{R(T - T_{ref})}\right) \quad (1)$$

In an acceleration model, the combined effect of temperature and humidity has to be included, possibly in form of an Eyring model [4]. Since those are the main impact factors on a VIP in use, the temperature - humidity dependence of pressure increase rates is the main work field at EMPA. It should be noted that both the edge seal and the area contribute to the total permeance of a VIP. Therefore, size effects have to be taken into account.

ii) Permeation of moisture is normally much faster compared to other atmospheric gases. WVTR in similar units can be 10^3 times the values for OTR or NTR [5]. On a long-term basis the internal moisture vapour pressure will often reach equilibrium with the environment, that is typically a range of 10 - 20 hPa. This is not a big problem concerning gas induced heat conduction in SiO_2-VIP. However, the increase in moisture content will raise the thermal conductivity of the core material by roughly 2/3 mW/(m K) per mass-% [6].

iii) Permeance of the edge seal will give faster permeation rates than calculated just for the barrier area. There is no evident model to quantify the edge seal contribution.

iv) On a long-term scale more complex processes such as polymer degradation, delamination, corrosion could be caused by the complex load factors. Those ageing mechanisms are hard to quantify in a short time. In addition to (accelerated) testing of components, long term experience with installed VIPs is needed.

EXPERIMENTAL SET-UP

Rise of internal pressure and accumulation of moisture in the core material are the two main effects influencing the long-term properties and the service life of VIP. Whereas moisture permeation can easy be measured just by weighing, there is no common test method for the internal pressure. A depressurisation-based method of measurement has been developed at EMPA: The pressure around a VIP sample is continuously reduced in a gas tight chamber. If the chamber pressure reaches the internal pressure of the VIP the flexible barrier film starts moving away from the core. The displacement is observed with a laser distance meter (Figure 3). By recording the chamber pressure and the distance of a fixed location on the main face of the VIP envelope the critical pressure can be determined with an accuracy of about 5 %.

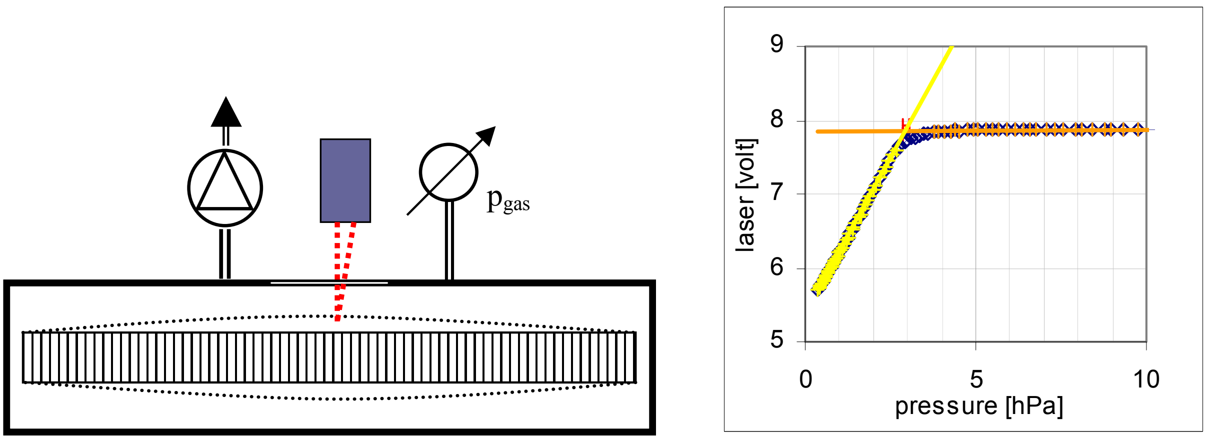

Fig. 3: Left: Principle of the internal pressure detection in a VIP (see text). Right: Evaluation of a distance-pressure diagram to determine the "critical" pressure (beginning of displacement of the barrier film).

RESULTS

First results of accelerated tests at elevated temperature and humidity conditions are summarised in this section. The specimens, typically with a size of 25 x 25 cm^2 ("small") and 50 x 50 cm^2 ("large") and a thickness of 2 cm, are commercial VIP products available on the Swiss market. The results give first indications of the service capabilities. However, more data are needed for an accurate determination of the acceleration functions.

To see the impact of hard conditions, a first series was performed on small VIP with a standard metallised polymer film envelope at 80°C, 80 % r.H. (80 / 80), followed by tests at 30 / 90, considered a more realistic application condition (see Figure 4). At 80 / 80 it is obvious that the pressure increase as well as the moisture accumulation is too large for an application. Interestingly, ageing with a cyclic load (8 h at 80 / 80, 4 h at 25 / 50) is faster than at constant 80 / 80. A strong correlation between internal pressure and moisture content is seen. So it can be argued that the internal pressure is mainly caused by water vapour. Another indication of the high moisture sensitivity is the behaviour at 80°C (ambient vapour pressure). The pressure increase rate is much smaller in that chase. Based on linear extrapolation a service life above 50 years can be expected up to 80°C (at ambient vapour pressure). At 30°C and 90 % r.H. the pressure increase rate is higher again. Linear extrapolation gives yearly increase rates higher than acceptable. On the other hand, when vapour pressure equilibrium is reached, moisture accumulation will stop (ca. 4 m-% at 60 % r.H., 15 m-% at 90 % r.H. [7]).

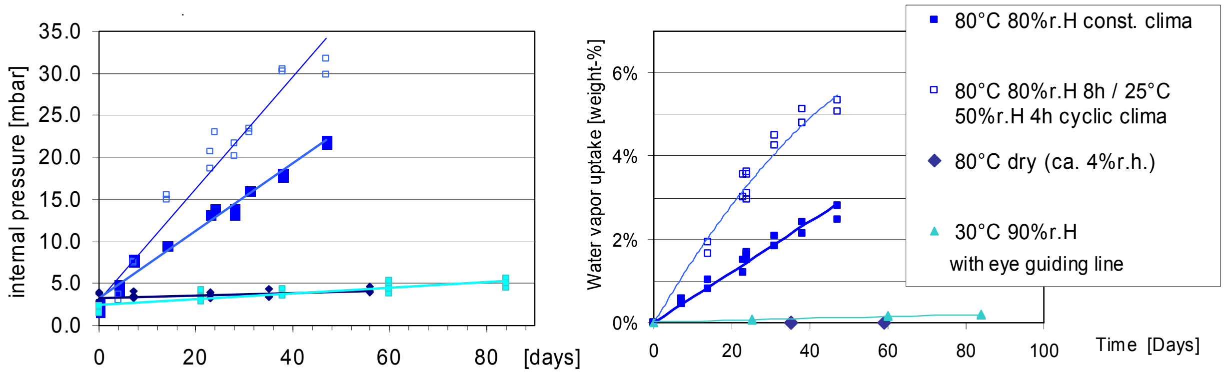

Fig. 4: Increase of internal pressure (left) and moisture content (right) in "small" VIP at elevated temperature / humidity. The measurements were done at room temperature after cooling down the samples for about 1 h. Discussion: see text.

To see the impact of envelope materials and edge, 3 products have been compared at 65°C, 75 % r.H., each with small and large size. Product MF1 with a 2-fold laminated metallised polymer film, product MF2 with a recent 3-fold laminated metallised polymer film barrier and, for comparison, product AF with a laminated 6 µm aluminium foil (Table 1).

As expected, product AF with the massive aluminium foil is very stable. Product MF1 with the standard barrier shows rather high permeation rates. A significant progress is reached with product MF2: The pressure increase is reduced by about a factor 5 to 6 compared to MF1. On the other hand, not too much improvement is observed with respect to moisture permeation.

As main surface area and volume are approximately proportional for constant thickness, a change in moisture content and pressure increase for different sample sizes indicates permeation through the edge. Combining the two data sets for a product, the ratio of edge to surface water vapour permeation for a 1 x 1 m^2 VIP is estimated to 1/3 (MF1) and 1/4 (MF2). For the small size of 25 x 25 cm^2 the edge leakage is almost equal to the gas flow through the area.

Size [cm x cm x cm]		M-%/a, extrapol. from 29 days	mbar/a, extrapol. from 29 days
AF	25x25x2	0.26% ± 0.04%	not detectable after 29 days
	50x50x2	0.19% ± 0.04%	not detectable after 29 days
MF1	25x25x2	8.6% ± 0.6%	167 ± 5
	50x50x2	6.1% ± 0.08%	124 ± 6
MF2	25x25x2	5.4% ± 0.04%	37 ± 2
	50x50x2	4.0% ± 0.03%	19 ± ?

Table 1: Comparison of products with different barriers and sizes. Shown is the extrapolated moisture content and pressure increase per year at 65°C, 75 % r.H. Comments see text.

DISCUSSION AND OUTLOOK

First measurements of the internal pressure and moisture content increase of different VIP products have been performed under various temperature and humidity conditions. They show that a laminated aluminium foil is by far the best barrier with respect to service life. However, the large edge heat loss of a "thick" aluminium envelope is hardly acceptable.

As an alternative polymer based metallised films are often used in today's VIP products. They are much more permeable, especially at elevated humidity-temperature conditions. Therefore current standard products cannot be recommended for building applications in potentially moist environment. Recent highest quality multiple layer metallised polymer barriers have clearly improved properties, though they are still rather sensitive to water vapour. Reasonable service life of high quality products can be expected for dry environment.

It can be argued that vapour pressure equilibrium with the environment will be reached as a worst case in a VIP. In that case, depending on the environment and VIP exposure, the thermal conductivity will be increased by some 2 up to 6 mW/(m K), i.e. to a level close to 10 mW/(m K) in moist conditions. Moreover, moisture related degradation such as delamination or corrosion within the envelope is expected to be faster in more permeable barrier films.

In future work "dry gas" and water vapour permeation will be investigated separately in more detail. Experimental data will be extended to obtain approved acceleration functions in the whole range of practical interest. On this basis service life will be predictable for the time dependent temperature-humidity loads taking effect in a particular building application.

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