Energy and Buildings 85 (2014) 592–596

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Vacuum insulation panels for building applications—Continuous challenges and developments

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ARTICLE INFO

Article history:
Available online 16 September 2014

Keywords:
Vacuum insulation
Barrier envelope
Permeation
Edge effect
Deterioration
Fibrous cores
Pyrogenic silica

ABSTRACT

This review paper gives the latest state of the art communicated during the 11th International Vacuum Insulation Symposium IVIS2013 and beyond. Although the largest application of the Vacuum insulation panels (VIPs) concerns the refrigeration industry (60%) and transport boxes (30%) and only a tiny amount is used in the building industry (10%), the number of scientific publications dealing with VIPs with regard to the latter dominate since more than a decade. The main topics addressed therein are the aging of the VIP as a whole as well as the role of the components, under different long term hygrothermal stress conditions. There is a clear expansion of VIP applications in buildings from primarily German speaking countries, toward Europe, and then to overseas. Recent years have witnessed an increasing confidence in this product among researchers and practitioners interested in energy efficient buildings worldwide.

1. Introduction

Vacuum on its own implies the suppression of heat transport by means of gas conduction and convection. Based on this principle vacuum insulation panels, have been developed since the first half of the last century leading to a patent as early as 1930, but first applications in buildings occurred in 1999 [1]. One of the reasons for this late appearance in the building insulation industry is the requirement on the durability of materials installed in buildings. In case of VIPs this puts an enormous expectation on the air and vapor tightness of the envelope to ensure vacuum for periods of 30 or 50 years according to the performance duration of buildings. This extreme air and water vapor tightness might have been possible using glass as it is the case for a Dewar flask [2] or thick metallic covering sheets. But the atmospheric pressure and the very large thermal bridge effect at the edges [3] were the reasons to search for different solutions namely those consisting of a core and a relatively thin and hence flexible envelope [4–6].

The steadily rising demand regarding reduction of energy consumptions in buildings requires continuously thicker insulation layers. VIPs as high performance insulation panels gained importance due to their 5 fold better performance compared to conventional insulation layers a situation which lead to the first Annex of the International Energy Agency IEA dealing with VIP's in the built environment [7,8]. The endeavor which started in 2002 with preliminary investigation regarding new envelope and core materials is going to continue within a new Annex of the IEA focusing into long-term performance of super-insulation in building components and systems [9] starting in mid-2014.

The publication of a remarkable number of review articles since 2007 up to this day [10–17] witnesses the continuous interest of mainly the building sector in VIPs. The present review summarizes the latest state of the art communicated during the 11th International Vacuum Insulation Symposium IVIS2013 and beyond including a stronger emphasis on the hygrothermal processes to which the VIP components and systems are subjected to, combined with the VIP practitioner and customers' interest. In order to allow an easier access to the reader, a subdivision into 3 chapters covering the VIP core, the VIP envelope and systems incorporating VIPs has been envisaged, allocating relevant information extracted from all contributions of IVIS2013 to the appropriate chapter.

2. The VIP core

Materials for VIP core should resist the mechanical pressure on the envelope from the atmospheric pressure of 1 bar (10^5 Pa) and should have a low effective thermal conductivity when evacuated. The dependence of the thermal conductivity on the gas pressure inside the VIP is commonly the main interesting property of the core in terms of enhanced heat transfer caused by aging. VIP's for the building application are commonly made of highly porous powders (e.g. pyrogenic silica) with added opacifiers to reduce

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http://dx.doi.org/10.1016/j.enbuild.2014.09.016
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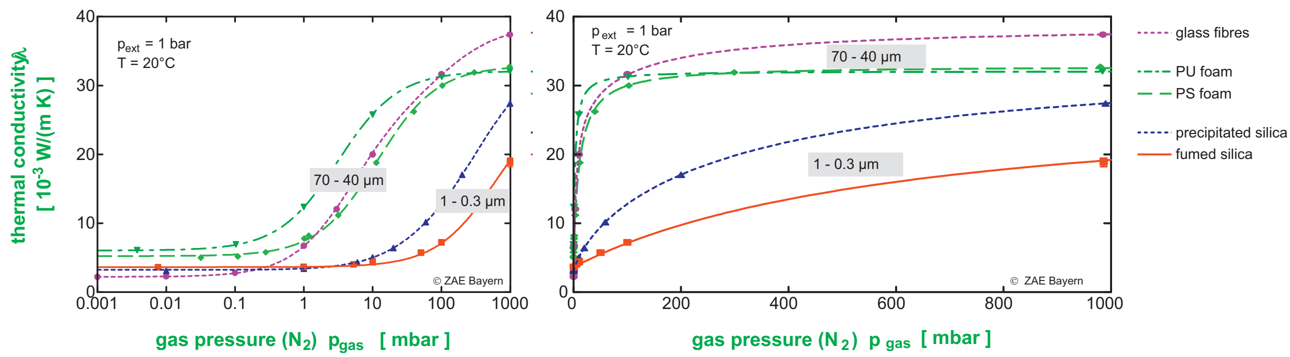

Fig. 1. Thermal conductivity of evacuated core materials as function of pressure in the commonly shown logarithmic scale (left) and in the linear scale to accentuate the nonlinearity (right), supplied by Heinemann [18]. This nonlinearity has a role in the aging discussion.

infrared transmission and fibers to reinforce the pressed boards. An overview of core materials including those for refrigeration and transport box applications has been given by Heinemann in his keynote lecture [18]. Fibrous cores (glass fibers) have a lower effective thermal conductivity when evacuated but the latter increases much faster with increasing pressure than it is case for pyrogenic silica. This has been presented by Fricke et al. [1] using a logarithmic scale and cited as such in most of the literature. Fig. 1 shows a linear representation of the thermal conductivity as function of pressure to increase awareness of different slopes visible in the linear representation. The difference between precipitated and fumed silica is due to difference in the pore structure (mainly pore size distribution). Further, open cell foam cores are also being used as core material mainly for transport box applications.

Asian companies started recently to consider VIP's with glass fiber core for use in building envelopes. Jung et al. [18] investigated the influence of fiber diameter on the center-of-panel thermal conductivity giving also indications regarding the influence of approximate fiber length, pore size and production method (Fig. 2). Three different production methods are presented in Fig. 2 each covering a certain range of fiber diameter and fiber length. Although the fibers produced by melt spinning (right side) achieve a lower thermal conductivity, their large pore size induces a faster increase in thermal conductivity with increasing pressure. This is a clear disadvantage for long term performance. The fibers produced by the flamed and the centrifugal method (left side) reach also low thermal conductivities but with smaller pore sizes. Hence, a better long term performance can be expected. Compared to pyrogenic silica these pore sizes are still larger by 2 decades.

Table 1
Parameters of six VIP samples, where T is the thickness of the core material, L the number of layers and λ the thermal conductivity. CF represents centrifugal, AF aerocor and FF short filament glass fibers.

Sample no.	Glass fiber	d (µm)	T (mm)	L	λ (mW/m/K)
1	70%CF + 30%AF	1.9–3.8	0.5	20	1.8
2	70%CF + 30%AF	1.9–3.8	1	10	2.1
3	70%CF + 30%AF	1.9–3.8	3	3	2.5
4	FF	8	0.5	20	1.9
5	FF	10	0.5	20	2.0
6	FF	13	0.5	20	3.4

The research team of Prof. Chen showed in their contribution Wu et al. [18] the influence of fiber distribution and fiber thickness summarized in Table 1 Many layers of thinner fibers aligned in a direction perpendicular to the heat flux (Fig. 3 bottom) results in a lower conductivity than few layers of thick disordered fibers (Fig. 3 top).

The mentioned team has a contribution of its own in this special issue on building application of fiber glass core VIP's in China. It has to be mentioned that the aspect of the long term performance of

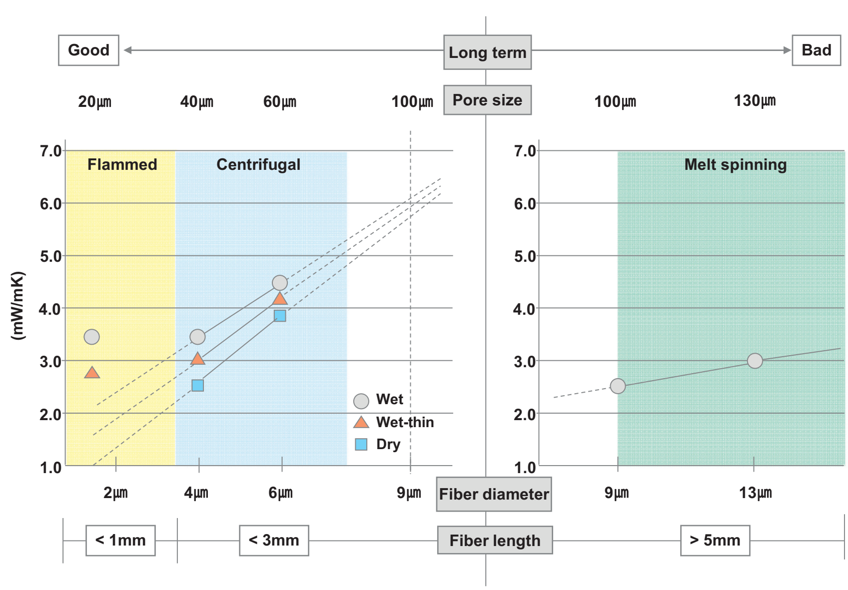

Fig. 2. Center-of-panel thermal conductivity of glass fibers as function of fiber diameter. The influence of approximate fiber length, pore size and production method are given as well. Supplied by Jung et al. [18].