



Thermal conductivity of VIP silica core at different levels of vacuum and external pressure

IVIS2015

12th International Vacuum Insulation Symposium - September 19 – 21, 2015, NUAA, China

Robust and Durable Vacuum Insulation Technology for Buildings

KTH

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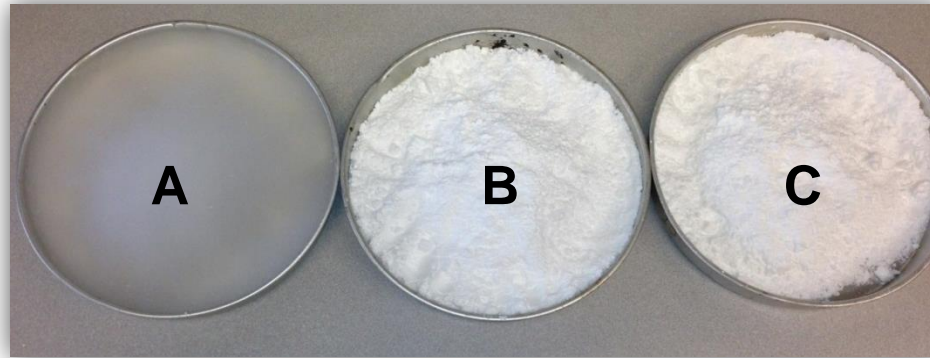
Thermal properties of core materials

Studies and evaluation of aerogel as core materials for VIP's with aim to:

- investigate new alternative core materials that may reduce the market price of the VIPs
- evaluate newly developed nanoporous silica, at different levels of gaseous pressure and mechanical loads
- modify the available measuring methods for testing thermal conductive properties of VIP core at different levels of gaseous pressure combined with mechanical loads



Materials



Sample ID	S_{BET} ($\text{m}^2 \text{g}^{-1}$)	PS (nm)	V_{tot} ($\text{cm}^3 \text{g}^{-1}$)	ρ_b (g cm^{-3})	Porosity (%)
A (P-100)	686	26	3.5	0.085	96.1
B	241	12	0.5	0.08	96.4
C	427	5	0.8	0.054	97.6

S_{BET} – BET specific surface area, PS- Pore size centred on maxima peaks in DFT pore size distribution, V_{tot} - total volume of pores between 1nm and 100 nm, ρ_b - tapped density, porosity is calculated on the basis of a skeletal density of 2.2 g·cm⁻³.

Sample A

Commercially available silica aerogel material
Visually translucent spherical aggregates

Actual density: 0.074 g·cm⁻³
Particle size: 0.01 - 4.0 mm
Pore size: Of about 20 nm

Sample B and C

New types of precipitated silica “powders”

Opaque particles

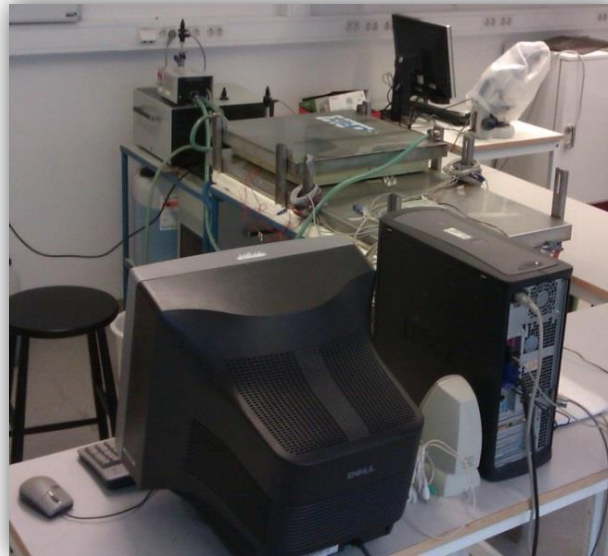
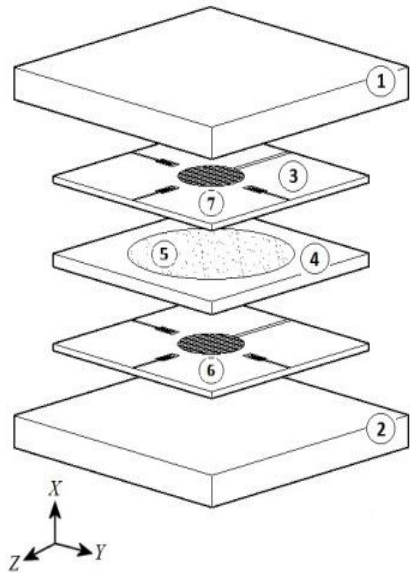
Actual density: 0.08 and 0.09 g·cm⁻³, respectively
Particle size: 1.0 – 100 µm (0.001 – 0.1 mm)
Pore size of 10 – 25 nm.

Measuring methods

A Transient Plane Source (TPS) method

A Transient Hot Bridge (THB) method

A stationary method with a hot plate apparatus

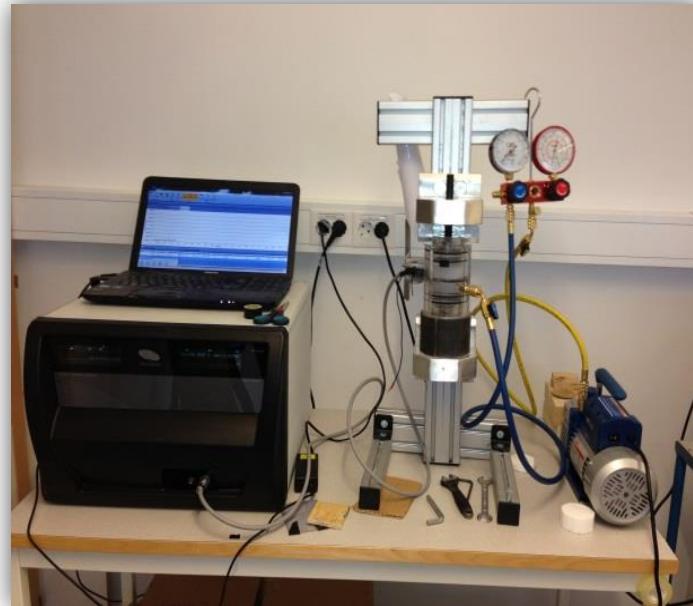
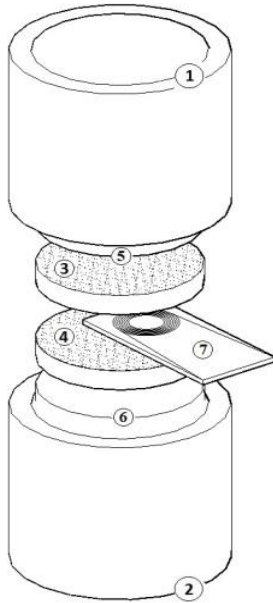


The Steady-state "Hot Plate apparatus"

Self-designed device

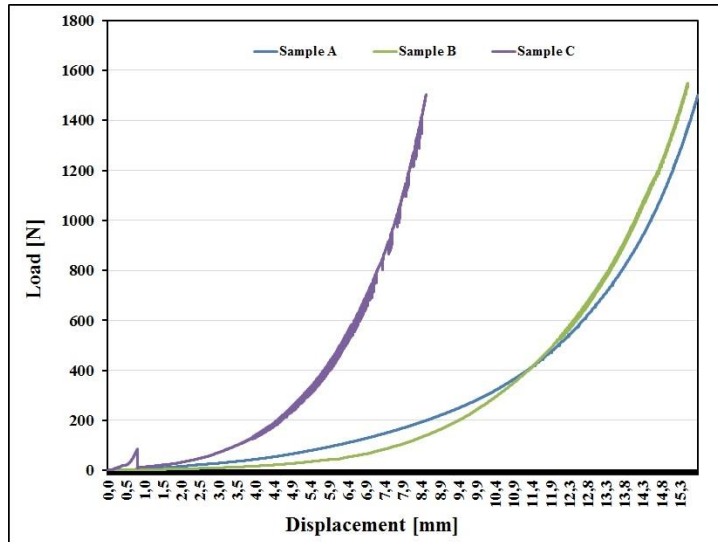
A new self-designed device, connected to a TPS instruments used for determining thermal conductivity of low density nano porous silica

- *by varying the gas pressure down to 0.1 mbar*
- *by external compression up to 4 bar*



Load vs displacement

The deformation of the specimen height as a function of an increasing load was monitored, resulting in a curve showing the load-displacement of a defined quantity of the samples (volume and mass).



The load–displacement curves acquired as the result of more than 250000 measurements, which were then converted to stress–strain curves

*Granular materials of similar size can show a great variation in fundamental mechanical properties in terms of their plasticity and elasticity, fracture strength and brittleness – **How about the lambda value and the effect of compaction?***

Measured thermal conductivity values

At atmospheric pressure and without application of external compression

Samples	Measuring procedure	Temperature, (° C)	Thermal conductivity, (mW m ⁻¹ ·K ⁻¹)	Thermal diffusivity, (mm ² ·s ⁻¹)	Duration	Precision	Accuracy
A (P-100)	Hot plate apparatus	25 ^C	19.5	-	12 Hours	-	-
	THB method ^a	25	23.5	0.1183	45-60 second	1%	5 %
	TPS method ^b	25	29.1	0.216	160 Second	1% ^d	5 %
B	Hot plate apparatus	25 ^C	36	-			
	THB method	25	36.4	0.2509			
	TPS method	25	38.7	0.328			
C	Hot plate apparatus	25 ^C	34.2	-	12 Hours	-	-
	THB method	25	38.5	0.2071	45-60 second	1%	5 %
	TPS method	25	38.8	0.249	160 Second	1% ^d	5 %

The greatest difference with the hot plate method being much closer to the data from the manufacturer, with a difference of only **1 %** while the THB and TPS methods differ by more than **16 %** and **32%**.

Sample A had a thermal conductivity of 19.7 mW m⁻¹K⁻¹, according to manufacturer and one previous work



Sample A:

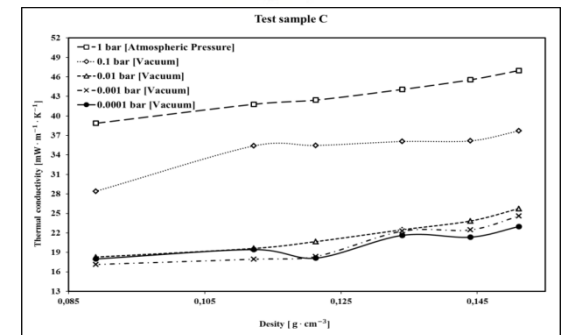
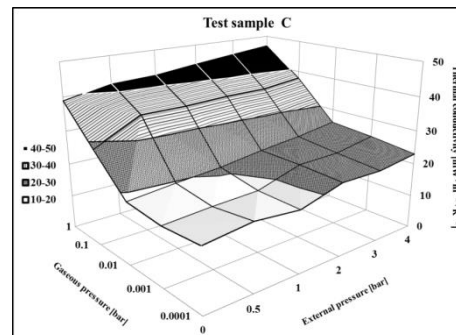
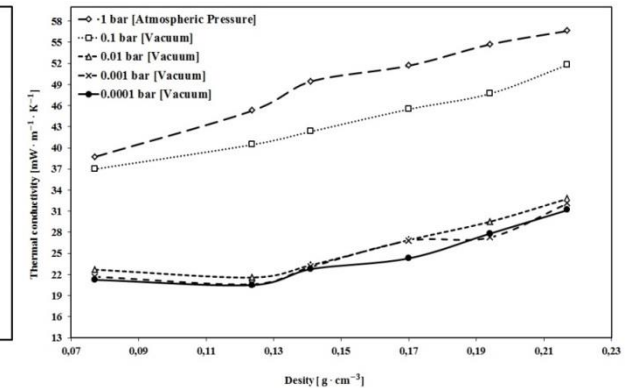
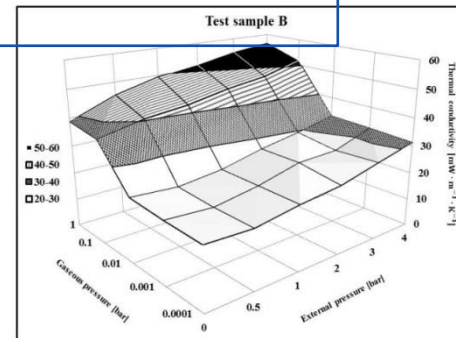
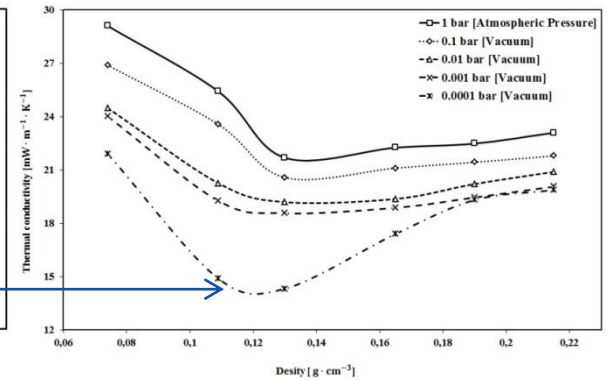
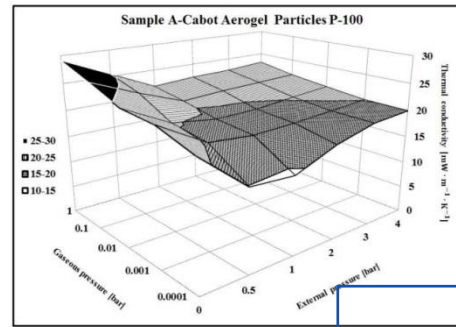
Actual density: $0.074 \text{ g}\cdot\text{cm}^{-3}$
 Particle size: $0.01 - 4.0 \text{ mm}$
 Pore size: Of about 20 nm

The sum of the contributions from solid and gas conduction, convection and radiative heat transfer is at a minimum

Sample B and C:

Actual density: 0.08 and $0.09 \text{ g}\cdot\text{cm}^{-3}$, respectively
 Particle size: $1.0 - 100 \text{ }\mu\text{m}$
 Pore size of $10 - 25 \text{ nm}$

The thermal properties are significantly related to the particle packing and compaction.



Conclusions

- The thermal properties are significantly related to the particle packing and compaction.
- In general, the stationary hot plate method
 - Simpler to conduct
 - Gives more accurate results
 - Nevertheless, the method is restricted to large and standard dimensions of the testing sample as well as long measuring time
- The transient methods offer other possibilities.
 - Significantly less measurement time
 - Possibility to use a much smaller test sample giving an advantage when producing new high cost materials
 - Physically smaller sensor of transient method gives opportunity to be connected to other devices
 - Provide information about the thermal diffusion coefficient of the material
- The TPS technique is less suitable for conducting the thermal conductivity measurements on low-density nanoporous silica powders. However, deviations in the results are minimal for densities above a limit at which the pure conduction becomes dominant compared to heat transfer by radiation.

Publications

Comparison of Different Methods for Evaluating the Thermal Conductivity of Granular Core Materials for VIPs

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KEYWORDS: Vacuum insulation panel apparatus, Transient Hot Bridge

SUMMARY: The superior thermal insulation properties of VIPs, their relative methods for developing low cost, fast and reliable methods for determining thermal conductivity for the VIPs in terms of time, sample size, design and cost together with an opportunity to carry out thermal loads. To verify the validity of this measurement, with a hot plate apparatus thermal measurements in this study mechanical loads while the method in some of the results indicate that silica materials with a comparative accuracy of the method.

1. Introduction

With a thermal conductivity between 0.005 and 0.01 W/mK, a vacuum insulation panel (VIP) is one of the most efficient thermal insulation materials available. A vacuum, from which the air has been evacuated, materials and envelopes in different precipitated silica have excellent thermal properties (Chen et al. 2010). good core material due to their low thermal conductivity as low as 0.005 value of about 0.07–0.15 g/cm³ (B) that can be as large as 1000 m² is a synthesis method and the silica on volume. As a result of these small thermal, acoustical and optical properties thermal conductivity of about 20 a material has porosity greater than 1



Review

Textural and thermal conductivity properties of a low density mesoporous silica material

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ARTICLE INFO

Article history:
Received 22 June 2013
Received in revised form 11 November 2013
Accepted 1 February 2014
Keywords:
Low density
Mesoporous silica
Thermal conductivity

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1. Introduction
2. Experimental
2.1. Materials
2.2. Preparation of mesoporous silica
2.3. Thermal conductivity measurements
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3. Results and discussion
3.1. Textural properties
3.2. Thermal conductivity
4. Conclusion
Acknowledgements
References

1. Introduction

Nanoporous materials offer some of the lowest thermal conductivity values owing to their unique low density, large surface area and high porosity (1).

Abbreviations: NIST, national density functional theory; PSD, pore size distribution; low surface area; Brunauer–Emmett–Teller equation; DSC, silica nanoporous material; ρ_a , actual density obtained by compressed powder; obtained by means of weighing.

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<http://dx.doi.org/10.1016/j.enbuild.2014.02.012>

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A study of the thermal conductivity of granular silica materials for VIPs at different levels of gaseous pressure and external loads

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ARTICLE INFO

Article history:
Received 16 March 2014
Received in revised form 17 September 2014
Accepted 19 September 2014
Available online 26 September 2014

Keywords:
Vacuum insulation panels (VIPs)
Core material
Mesoporous silica aerogel
Thermal conductivity measurements
Transient and stationary methods
Hot plate apparatus
Transient Hot Bridge (THB) method

1. Introduction

A vacuum insulation panel consists of an impermeable envelope enclosing a porous core from which the air has been evacuated. A typical VIP panel, as known today, is made out of a multilayer envelope of aluminum and polymer film and a core of fumed silica. There are however many possibilities of combining alternative core materials and envelopes in different typologies as described in previous work [1].

1.1. Description of the VIP core materials

Nanoporous (pores with a length scale of 1–100 nm) silica materials make excellent candidates for VIP core material due to their unique thermal physical properties [2]. Aerogel, fumed silica and precipitated silica offer low thermal conductivity values owing to their low density, large surface area and small pores in the nanoscale range [3,4]. Recommendations for the definition of pores according to their specific size have been established by the International Union of Pure and Applied Chemistry (IUPAC) [5].

Aerogel for example, has a large surface area ($\sim 1000 \text{ m}^2 \text{ g}^{-1}$) and pores in the range between 5 and 100 nm depending on the synthesis method and the silica source used [6]. These pores occupy about 80–95% of the total bulk volume. As a result of the small pores and high porosity, aerogels exhibit extraordinary physical, thermal, acoustical and optical properties. A bulk density as low as 0.003 g cm^{-3} has been reported, while values of about $0.07–0.15 \text{ g cm}^{-3}$ are more common [6,7]. A thermal conductivity of $0.012–0.015 \text{ W m}^{-1} \text{ K}^{-1}$ at ambient pressure has been established for granular beds [6,8]. Fumed silica, on the other hand, has porosity greater than 90% and a bulk density in the range of $0.06–0.22 \text{ g cm}^{-3}$ [7,9]. The material also has a specific surface area in the range of $100–400 \text{ m}^2 \text{ g}^{-1}$ which varies with the particle size and a maximum pore size value of about 200 nm, as reported by Gierke et al. [10]. A thermal conductivity of about $20 \text{ mW m}^{-1} \text{ K}^{-1}$ at atmospheric pressure has also been shown for granular beds [7,8]. Despite the obvious technical advantages of aerogel materials, the utilization as thermal insulation in the building industry is limited, partly due to the high market price [4,6–8]. The work of Venkateswara et al. [10] and Scherer [11] describes the current manufacturing processes of silica aerogel thermal insulating materials as laborious and uneconomical. For this reason, much work has been done on the development of low cost aerogels with thermal performance comparable to that of typical VIPs (see [12–15], in a recent work,

[I] P. Karami, K. Gudmundsson, Comparison of different methods for evaluating the thermal conductivity of granular core materials for VIPs, Accepted for oral presentation and publication in proceeding of the 10th Nordic Symposium on Building Physics (NSB), Lund, Sweden, 15–19 June 2014.

[II] E. Twumasi Afriyie, P. Karami, P. Norberg, K. Gudmundsson, Textural and thermal conductivity properties of a low density mesoporous silica material, Energy and Buildings 75 (2014) 210–215.

[III] P. Karami, E.T. Afriyie, P. Norberg, K. Gudmundsson, A study of the thermal conductivity of granular silica materials for VIPs at different levels of gaseous pressure and external loads, Energy and Buildings 85 (2014) 199–211.

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<http://dx.doi.org/10.1016/j.enbuild.2014.02.012>

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