37

Forschungsinstitut für Wärmeschutz e.V. München

MITTEILUNGEN

Reihe I:
Allgemeine Fragen des Wärme- und Kälteschutzes

Determination of the internal pressure of vacuum insulation panels with the envelope lift-off technique – methods for analysing test data

Sebastian Treml
Max Engelhardt
Christoph Spengard
Wasyl Butko

Sonderdruck aus:
Energy & Buildings 184 (2019)

FIW München

Energy & Buildings 184 (2019) 44–52

Contents lists available at ScienceDirect

Energy & Buildings

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

Determination of the internal pressure of vacuum insulation panels with the envelope lift-off technique – methods for analysing test data

Sebastian Treml*, Max Engelhardt, Christoph Sprengard, Wasyl Butko

Forschungsinstitut für Wärmeschutz e. V. München, Lochhamer Schlag 4, DE-82166 Gräfelfing, Germany

ARTICLE INFO

Article history:
Received 27 April 2018
Revised 16 October 2018
Accepted 15 November 2018
Available online 30 November 2018

Keywords:
Vacuum insulation panels
Envelope lift-off technique
Internal pressure

ABSTRACT

For vacuum insulation panels the internal pressure is crucial for the thermal performance of the panel. Depending on the pore size of the core material the internal pressure is directly connected with the thermal conductivity. Compared to the determination of thermal conductivity, the measurement of the internal pressure can be performed very quickly, what makes it ideal for quality check purposes. Also for the proof of durability by applying an artificial ageing procedure and in the case of development of new high barrier film materials or production methods, the precise determination of internal pressure is very important. The reference method for internal pressure measurements on VIPs with mainly pyrogenic silica as core material is the so called envelope lift-off technique. For this method the atmospheric pressure around the VIP is lowered subsequently and the pressure as well as the deflection of the envelope is observed. As soon as the surrounding pressure is lower than the internal pressure of the VIP the envelope lift-off from the core material. To calculate the internal pressure of the VIP the measured curve of pressure as a function of the envelope displacement is evaluated. Up to now no detailed information of how to process the test data to achieve the best possible accuracy is available. To avoid a user influence, automated test data analyses based on adequate algorithms to identify the internal pressure are favorable. This paper describes algorithms for two methods to evaluate the observed data, which are referred to as tangent method and triangle method. The algorithms are tested on a set of internal pressure measurements on VIPs with pyrogenic silica core and flexible laminate envelopes. Both methods are suitable for automated analysis of test data.

1. Introduction

Due to the extremely low thermal conductivity of vacuum insulation panels (VIP), these boards are particularly suitable for use in numerous technical applications where only little space is available, but a high quality of thermal insulation is required e. g. refrigerators and transport boxes. Also, in the construction sector, the use of VIP becomes more common, latest since it has become clear that the energy efficiency of buildings is a crucial point to achieve the EU-wide and nationally declared energy and CO_2 reduction goals. In comparison to conventional thermal insulation materials like rigid foams or mineral wool the thickness can be reduced significantly, what is especially of great importance in urban structures with high priced living spaces and in the events of refurbishments of old buildings.

In the construction sector, especially the durability of the thermal performance of VIP is crucial to guarantee a life-long energy saving potential and to avoid structural damage or hygienic and hygric problems. The climatic impacts on the panels are much more challenging than in most common technical applications, e. g. in refrigerators with their constantly rather low temperatures on one side of the VIP. In building elements, a variation of temperature and humidity following day- and year-cycles will apply and also the absolute temperatures can be significantly high, reaching 70 °C in façade and roofing applications in the climates typical for Germany. Also, the expected service life time is usually higher than in technical applications as it should be in line with the life time of building elements that are 25 – 50 years at the least.

The thermal performance of VIP is directly connected with their internal pressure that should be kept low enough to suppress conductive heat transfer of the gas inside the porosities. Depending on the pore diameters, a maximum internal pressure of 50 – 100 mbar (fumed silica) respectively 1 mbar (fibre cores) shall not be extended during the service life time. VIP are used in the construction sector for just about 10 years now with official declaration values (like DIBT) and 19 years when including pioneer applications, so limited long-time behaviour studies can be derived from practical applications. Therefore, artificial ageing is performed to de-

* Corresponding author.
E-mail address: treml@fiw-muenchen.de (S. Treml).

https://doi.org/10.1016/j.enbuild.2018.11.027
0378-7788/

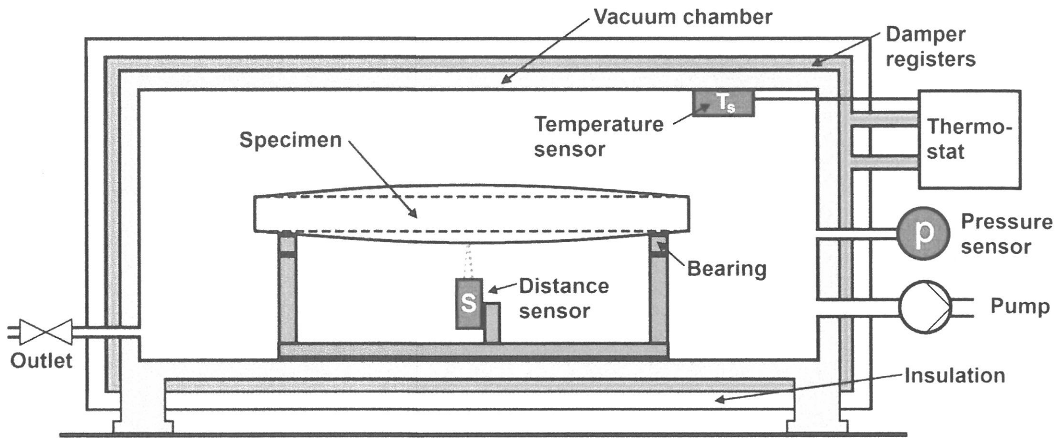

Fig. 2. Test setup consisting of vacuum chamber with damper registers to control ambient test conditions, pressure sensor, vacuum pump, laser distance sensor and specimen on test rack.

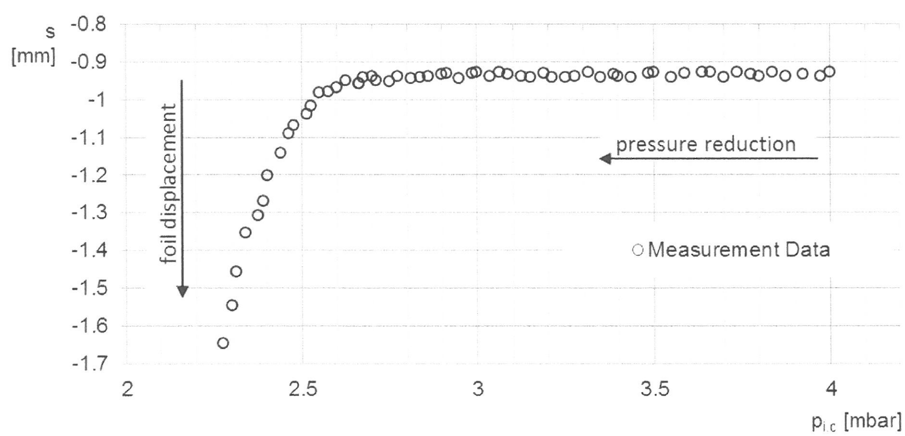

Fig. 3. Exemplary measurement data $s(p_{i,c})$ determined on a VIP with 15 mm thickness, sample rate 1 Hz.

ous curve that ends at least for the evaluated time-frame in a linear behaviour. The tangent method defines p_i by the coordinates of the point of intersection between the two tangents (p_i/s).

Further information about the implementation of the tangent method is not published. It can be assumed that individual ways of processing the data are used. Due to individual characteristics of real measurement data, an influence of the individual method chosen for data evaluation and in some cases a user influence is likely to occur, especially when the tangents are fitted visually to the data.

3. Materials and methods

In the following chapter the material used for validation, the equipment for the measurement itself and the development of two different algorithms for data analysis (tangent method and triangle method) are presented.

3.1. Material used for the validation of the proposed algorithms

For validation of the performance of the introduced algorithms both methods were applied to a set of internal pressure measurements of 30 VIP with a thickness of 15 mm. The results determined with both methods of data evaluation are shown afterwards. The investigated panels were tested five months after production to eliminate possible initial changes in internal pressure. The core consists of fumed silica. In the production process, all panels were evacuated to the same internal pressure. All specimens stem from the same production lot.

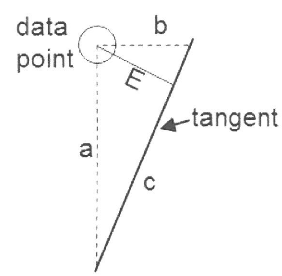

Fig. 4. Residual in the direction of the ordinate (a), in the direction of the abscissae (b) and the residual perpendicular to the tangent (E) as calculated according to Eqn. (2).

3.2. Equipment used and description of the setup

In the following the equipment for determination of $s(p_{i,c})$ is described. To reduce the gas pressure in the vicinity of the VIP, a rectangular vacuum chamber with dimensions of $1000 \times 1000 \times 400$ [mm] is used. The chamber is equipped with flanges for a vacuum pump, pressure sensor, and data port to connect the internal laser distance sensor. The chamber is temperature controlled to maintain constant temperatures while testing. Five sides of the chamber are encased with damper registers connected to a thermostat. The temperature of the chamber is set to 20 °C. The steady-state control accuracy of the chamber temperature is below ± 1 K. To reduce the energy demand, the damper registers are insulated with flexible elastomeric foam insulation.

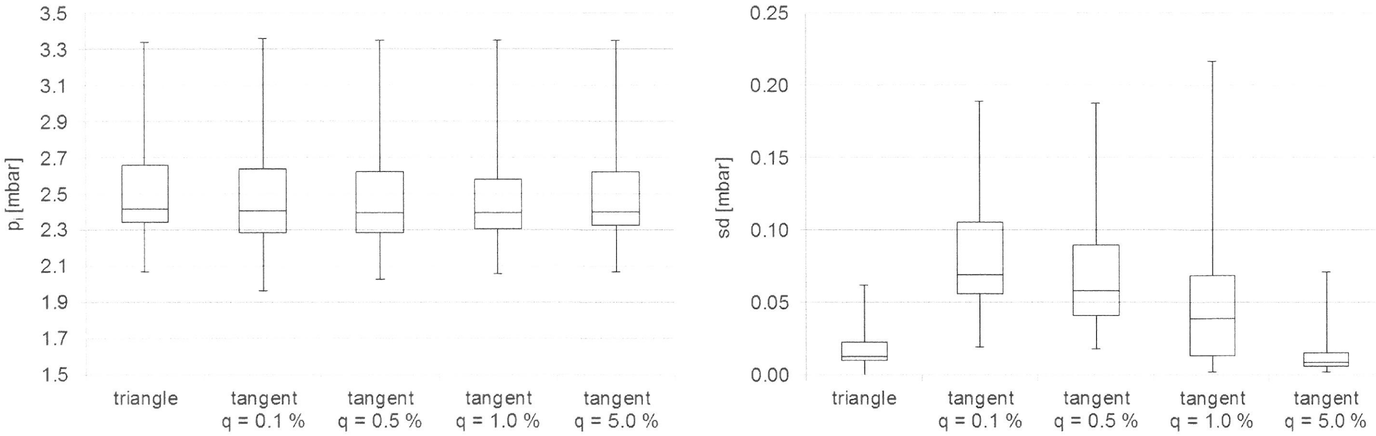

Fig. 7. Boxplot of results of internal pressure of 30 VIP (each result as part of the boxplot was calculated as the mean value of 3 – 4 lift-off sequences for each panel), box spans quartile group 2 and 3 and indicates the median, upper whisker represents quartile group 4, lower whisker represents quartile group 1, data evaluated with triangle method and tangent method with different levels of q; Left: Boxplot of the mean values of p_i (N = 30), Right: Standard deviation (sd) of p_i over the 3 – 4 lift-off sequences for each panel (N = 30).

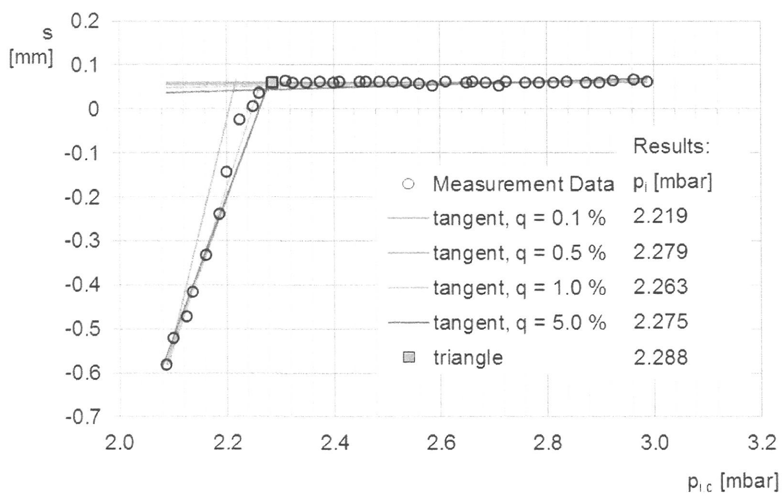

Fig. 8. Typical test data with straight flanks and a sharp kink in the bent transition zone, including results for the tangent method with different threshold values for q (0.1%, 0.5%, 1.0%, 5.0%) and the triangle method.

to gravimetric effects that may influence the test results if the envelope displacement is observed from the top side.

The gas pressure in the chamber and the distance signal from the laser sensor are logged simultaneously at a minimum frequency of 1 Hz. Five pressure drops (until VIP envelope displacement is above 1 – 2 mm) are conducted. The chamber is partially ventilated between these pressure drops (pressure increase of ~ 10 mbar).

3.3. Development of algorithms for data analysis

The physical principle of the lift-off method is the reverse of the relative pressure difference between the internal pressure of the observed panel and the evacuated environment that leads to a lift-off of the envelope. The recorded function $s = f(p_{i,c})$ is analysed by geometrical aspects then to define a unique and characteristic result. For this purpose two different algorithms were developed that are explained in principle. Both methods can be implemented with any adequate script language.

Separate analysis of parts of the measurement data each containing a lift-off sequence between the short-duration ventilations (that allow the envelope to get in proper contact to the core material again) of the vacuum chamber is conducted for both methods. The clipped measurement data is plotted as a function of distance over internal pressure of the vacuum chamber $s(p_{i,c})$. To enhance understanding the following analysis are performed on exemplary real measurement data. Fig. 3 shows the raw measurement data used (one lift-off sequence, $s(p_{i,c})$). The data was determined with the measurement equipment explained in chapter 3.2 on a VIP with 15 mm thickness.

3.3.1. Implementation of the "tangent method" for data analysis

To find the linear sectors and the two tangent lines a linear regression analysis of the measurement data starting with two data points (values of pressure and displacement) and increasing the included data point by point is conducted. This is done from the beginning of the data sequence onwards for tangent A and from the end of the data backwards for tangent B.

With each increment of the number of data point in the regression, the sum of error squares (SSE) divided by the number of data points is calculated (Q-values) (Eq. (1)).

$$Q = \left(\frac{SSE}{n^2}\right) \quad (1)$$

SSE: sum of squared errors of regression

n: number of data points included in the regression

The steeper the slope of the left flank of the measurement data pattern occurs, the bigger the residuals in the direction of the ordinate become (Fig. 4).

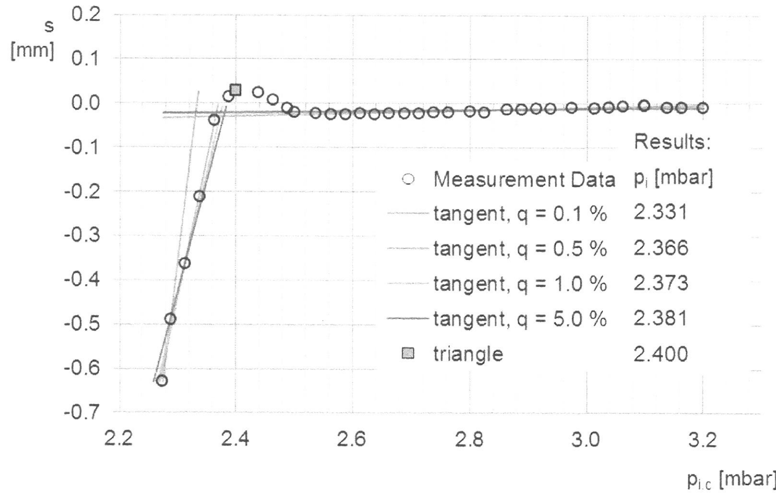

Fig. 10. Typical test data with straight flanks and reciprocal envelope behaviour before the lift-off, including results for the tangent method with different threshold values for q (0.1%, 0.5%, 1.0%, 5.0%) and the triangle method.

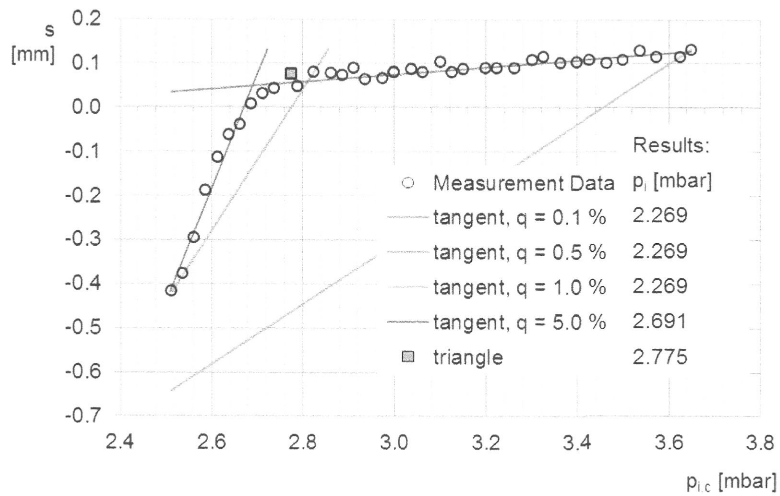

Fig. 11. Typical test data with a higher spreading of individual measurement data points, including results for the tangent method with different threshold values for q (0.1%, 0.5%, 1.0%, 5.0%) and the triangle method.

Fig. 7 shows a boxplot for the results of internal pressure obtained on the 30 VIPs investigated. All panels had an internal pressure of around 2.5 mbar. However, every VIP is to be seen as an individual test specimen. Therefore only a comparison of the spreading of the results obtained with different kinds of data evaluation is made. Both triangle method and tangent method show very similar median values and distribution of internal pressure over the investigated panels (Fig. 7, left).

A comparison of the standard deviation between the three to four lift-off sequences that were evaluated is shown on the right in Fig. 7. One can see that the triangle method and the tangent method with $q = 5\%$ show the lowest standard deviations within each panel, and therefore, the most homogeneous results for the internal panel pressure. With decreasing values of q the standard deviation is rising, and the distribution of the values spreads more. Again, it is worth noting that this does only reflect the variance of the results obtained on one panel in different lift-off sequences. No information about the deviation of the calculated result of p_i from the true value of p_i can be derived out of this. In any case the standard deviation within one series of lift-off sequences is low, compared to the mean value obtained as the result of the series. This indicates that the applied technique of handling the samples, as well as the described data evaluation method provides a sufficient repeatability.

4.2. Sensitivity of the tangent method and triangle method to typical test data pattern

To enhance understanding of the effects and interdependencies between the value of q and the quality of the data, different typical data pattern are shown and the results are discussed.

A typical test data pattern, consisting of straight flanks with a relatively sharp kink in the bent transition zone is shown in Fig. 8. The variation of results between tangent method and triangle method is low, only the tangent method with $q = 0.1\%$ leads to a significant lower determination of p_i. This is due to only two data points included in the left tangent, what determines the slope of this tangent. This effect can be seen quite often for low values of q, both for left and right tangents. If this occurs for the right tangent the effect on the position of the intersection of the two tangents is the more significant, the lower the slope for the left tangent is.

Fig. 9 shows typical test data with straight flanks, but a more curved transition zone. Again the tangent method with $q = 0.1\%$

[10] H. Schwab, Vakuumisolationspaneele – Gas- und Feuchteeintrag sowie Feuchte- und Wärmetransport. Dissertation, Julius-Maximilians-Universität, Würzburg, 2004.
[11] H. Schwab, U. Heinemann, A. Beck, H.P. Ebert, J. Fricke, Dependence of thermal conductivity on water content in vacuum insulation panels with fumed silica kernels, J. Therm. Env. Build. Sci. 28 (2005) (2005) 319–326.
[12] H. Schwab, U. Heinemann, A. Beck, H.P. Ebert, J. Fricke, Prediction of service life for vacuum insulation panels with fumed silica kernel and foil cover, J. Therm. Env. Build. Sci. 28 (2005) (2005) 357–375.
[13] H. Simmler, S. Brunner, Vacuum insulation panels for building application. Basic properties, ageing mechanisms and service life, Energy Build. 37 (2005) (2005) 1122–1131.
[14] C. Sprengard, M. Spitzner, Untersuchungen zu Alterung und Wärmebrücken bei Vakuum-Isolations-Paneelen (VIP) für Bauanwendungen, Bauphysik 33 (2011) (2011) 234–242 Heft 4.
[15] C. Sprengard, A. Holm, Numerical examination of thermal bridging effects at the edges of vacuum-insulation-panels (VIP) in various constructions, in: Proceedings of IVIS 2013, 11th International Vacuum Insulation Symposium – 19th – 18th September, Empa Switzerland, 2013.
[16] C. Sprengard, A. Holm, Numerical examination of thermal bridging effects at the edges of vacuum -insulation-panels (VIP) in various constructions, Energy Build. 85 (2014) 638–643.
[17] B. Yrieix, E. Pons, New method to assess the air permeance into vacuum insulation panel, Vacuum 148 (2017) 265–271.