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SciVerse ScienceDirect
Energy Procedia 30 (2012) 255 – 259
Energy Procedia

SHC 2012

On vacuum insulated thermal storage

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Abstract

This paper presents a first state of the art review on vacuum insulated thermal tanks. On the one hand this contribution gives a short introduction on the physics of vacuum insulations, used in existing thermal hot water tanks. On the other hand it presents the two common concepts of the Center for Applied Energy Research in Munich (ZAE) and the University of Applied Science in Nuremberg.

Keywords: Thermal storage; vacuum; insulation

1. Introduction

Today, the insulation for small and middle-sized thermal hot water storage is not as good as it should be. This is especially caused by higher investment cost for better insulation and the bounded amount of space particularly with small tanks. However, recent studies have focused on high insulated thermal storage [1–3]. There are two common concepts in the use of vacuum insulation for thermal hot-water storage. On the one hand, the Bavarian Center for Applied Energy Research (ZAE) in Munich uses an evacuated double vessel filled with pearlite [4] and on the other hand, the Ohm University uses vacuum insulation panels (VIP) [5]. Both insulation concepts are based on the Knudson effect and will be explained below. With vacuum insulation the thermal conductivity is lowered by a factor of 6 to 10 [6], compared to conventional insulation materials, like expanded polystyrene or mineral wool. Both concepts are adoptions of already existing technologies of cryogenic tanks and passive houses. Nevertheless, the use of vacuum insulation for thermal hot-water storage cause new problems due to higher temperatures and moisture [5].

doi:10.1016/j.egypro.2012.11.030

2. Vacuum insulation

The physics of the heat transfer trough insulation materials is well known and according to Schwab [7] it can be described with the sum of three heat transfer processes:

$$\lambda_{ov} = \lambda_r + \lambda_s + \lambda_g (+\lambda_{coupling}) \qquad (1)$$

where λ_{ov} is the total heat transfer, λ_r is the heat transfer via radiation, λ_s is the heat transfer though the solid of the core, λ_g is the heat transfer due to gas conductivity [5].

Sir James Dewar (1892) proposed the lowest heat transfer via gas conductivity can be achieved by a perfect vacuum [8]. Therefore a vacuum reduces the thermal conductivity of most traditional insulation materials [5, 8].

However, the kinetic gas theory teaches the thermal gas conductivity is independent of gas pressure. Rath [9] explains that the number of gas molecules and thus the number of collisions between gas molecules within an unrestricted gas is directly proportional to the pressure. In contrast the amount of energy transferred per collision between molecules is inversely proportional [9]. Thus, both effects cancel each other out [10]. According to Kennard [11] and Baetens [8] the gas conductivity in porous materials can be described as:

$$\lambda_g = \frac{\lambda_{g,0}}{1 + 2\beta K_n} \qquad (0.1)$$

with

$$K_n = \frac{mfp}{\delta} \qquad (0.2)$$

and

$$mfp = \frac{k_B T}{\sqrt{2}\pi d_g^2 p_g} \qquad (0.3)$$

where K_n is the Knudsen number, δ is the characteristic size of pores, mph is the mean free path, β is a constant between 1.5 and 2.0 characterizing the efficiency of energy transfer when gas molecules hit the solid structure [8], k_B is the Boltzmann constant, T the absolute temperature, d_g the diameter of the gas molecules and p_g is the gas pressure [5]. According to Schwab [7] the heat transfer through gas for Knudsen numbers in the transition zone (K_n~1), where the mean free path is in the same order as the pore diameter, can be written as:

$$\lambda_g = \frac{\lambda_{g,0}}{1 + \frac{p_{1/2g}}{p_g}} \qquad (0.4)$$

Schwab [7] also gives further equations for the median pressure $p_{1/2g}$, $p_{g,0,}$ and for Knudsen numbers small and higher than one [5]. The theoretic thermal conductivity calculated with equitation 1.5 and moreover the thermal conductivity of vacuum insulation materials are drawn in figure 1 [5].

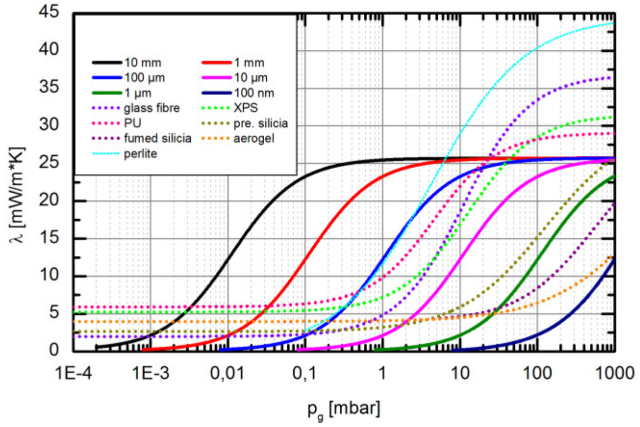

Fig. 1. The thermal conductivity λ of air is a function of the gas pressure p_g. The smaller the pore diameter the higher the pressure to achieve certain thermal conductivity. Fumed silica, as used in VIP, has a pore diameter of 200 nm [7]and perlite, as used in the ZAE tank, has a grain size up to 2 mm [12], pore size diameters of 0,1 mm can also be found. (redrawn from [4, 8, 10]) [5]

3. Concepts of vacuum insulated storage

The ZAE and Hummelsberger has been researching an vacuum insulated hot-water storage with expanded perlite between an evacuated double vessel [1]. The prelate is filled between the gap of the two cylindrical tanks. As shown in figure one the pressure has to be lowered to 0.01 mbar to achieve the Knudsen effect. Since decades, this concept is already used for liquid gas tanks at tempretures between 20 K and 90 K [1].

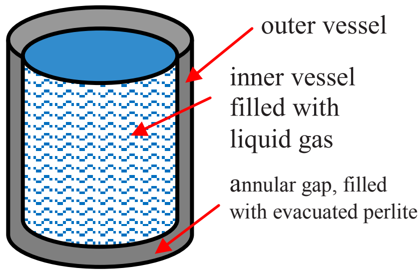

Fig. 2. Schematic sketch of a typical cryogenic storage for liquid gases (redrawn from [1]) [5]

The pressure-dependency gas conductivity of evacuated perlite with a density of 55 kg/m³ was measured by the ZAE. (see figure 1) The thermal gas conductivity of evacuated perlite was measured also in the temperature range between 20 °C and 150 °C and with different densities between 55 kg/m³ and

95 kg/m³) [1]. For the experimental storage the ZAE had chosen perlite with a density of 92.4 kg/m³. The filled gap was evacuated to a pressure of 0.08 mbar. Afterwards the 15.5 m³ storage was filled with hot water with a temperature of 86.5 °C. Within an interval of 10 days the cooling rate had been determined. The ZAE found an overall cooling-rate of 0.23K/day including all thermal bridges. Therefore the effective u-value for the experimantel storage is 0.05 W/(m² K) [5]. A further theoretical study on evacuated double wall vessels with opaque insulation materials and also with foils was done by Altenburg [2].

The Georg-Simon-Ohm-University of applied since is researching a different kind of vacuum insulated thermal storage. In dependence of vacuum insulated passive houses [13], the OHM university uses an concrete tank with vacuum insulation panels (VIPs) [14]. Therefore VIPs of Variotec has been used with a fumed silica core with a pressure of 1 to 3 mbar [5]. (see figure 1) Theoretical analyses leads to an effective u-value of 0.5 W/(m² K). The experimental storage has been built in Sengenthal with an volume of 100 m³. Further information can be found in this with the topic “Vacuum Insulation Panels – A Promising Solution for High Insulated Tanks”.

4. Discussion

An overview of long-term thermal storage and the state of the art in modeling was published by Ochs [15]. It is shown that long-thermal storing is nearly exclusively involved with huge thermal storages [5]. Amongst other things the surface-volume-ratio is the lion`s share. As shown in figure 3 smaller thermal storage has much higher surface-volume-ratios. According to this fact smaller thermal storage with up to 100 m³ have to be insulated wither smaller u-values for the use of long-term storing.

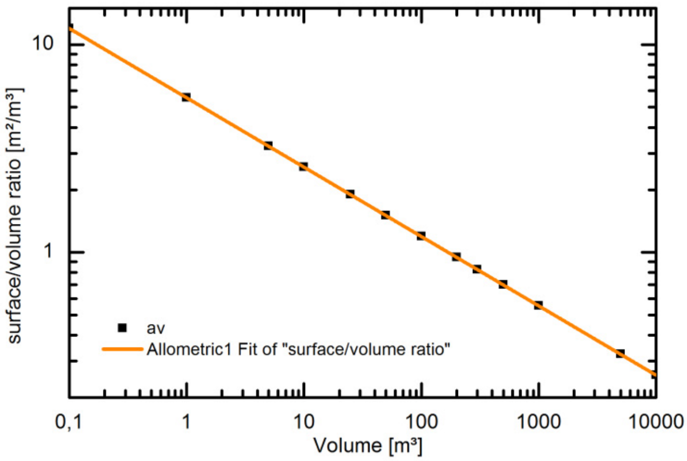

Fig. 3. Surface-volume-ratio of optimized cylindrical storage tanks [5]

However, the u-values of thermal storage on the solar thermal market, as published in the journal Sun, Wind and Energy [16] with volumes up to 100 m³ are quite too high for long-term storing [17].

5. Conclusion

This review shows the potential of vacuum insulation materials in the field of small and middle-szied thermal storage. As yet, two basic concepts were developed by the ZAE and the OHM to use vacuum insulations for hot water tanks. Both concepts are promising to reduce the thermal losses of small thermal stores tremendous [5].

Acknowledgements

This study was supported by the Bavarian Ministry of Science, Research and Art.

References

[1] Beikircher T, Buttinger F, Demharter M. Entwicklung eines superisolierten H20-Langzeit-Wärmespeichers. In: M. Rommel, editor. *21. Symposium Thermische Solarenergie*. Regensburg: OTTI 2011: 511–516.

[2] Altenburger F et al. Theoretische Untersuchungen zur Entwicklung eines Wasserwärmespeichers mit Vakuumdämmung. In: M. Rommel, editor. *21. Symposium Thermische Solarenergie*. Regensburg: OTTI 2011: 505–510.

[3] Fuchs B, Hofbeck K. Vacuum Insulated Thermal Storage in Sengenthal. In: Eurosolar, editor. *5th International Renewable Energy Storage Conference 2010*. 2010.

[4] Beikircher T, Buttinger M, Demhart M, Schölkopf W. Super-insulated long-term storage. In: I. S. E. S. ISES, editor. *ISES Solar World Congress*. 2011.

[5] Fuchs B, Hofbeck K. On Vacuum-Insulated Thermal Storage. In: Eurosolar, editor. *6th International Renewable Energy Storage*. 2011.

[6] Fricke J, Schwab H, Heinemann U. Vacuum Insulation Panels – Exciting Thermal Properties and Most Challenging Applications. *Int J Thermophys* 2006; **27** *(4)*: 1123–1139.

[7] Schwab H. *Vakuumisolationspaneele: Gas- und Feuchteeintrag sowie Feuchte- und Wärmetransport*. Würzburg: 2004.

[8] Baetens R et al. Vacuum insulation panels for building applications: A review and beyond. *Energy and Buildings* 2010; **42** *(2)*: 147–172.

[9] Rath D. Wärmetransport in evakuierten Dämmsystemen, *Dissertation*. Dortmund: Universität Dortmund 1989.

[10] Tenpierik MJ. VIP A B C: Vaccum Insulation Panels Applied in Building Constructions, *Dissertation*. Delft (NL): TU Delft 2009.

[11] Kennard EH. *Kinetic theory of Gases: with an Introduction to Statistical Mechanics*. New York: Mc-Graw-Hill 1938.

[12] Europerl. *Datenblatt "Technoperl"*. St. Pölten (AT): 2011.

[13] Zwerger M, Klein H. Integration of VIP's into External Wall Insulation System. In: S. F. L. f. M. T. a. R. Empa, editor. *7th International Vacuum Insulation Symposium*. Duebendorf (CH): 2005: 173–180.

[14] Fuchs B, Boenig J, Hofbeck K, Faulstich M. Vacuum Insulated Thermal Storage. In: N. R. C. C. NRC, editor. *Vacuum Insulation Panels*. 2011: 83–88.

[15] Ochs F. *Modelling large-scale thermal energy stores*, Berichte aus der Energietechnik. Aachen: Shaker 2010.

[16] Mäueler D. Marktübersicht Solarspeicher. *Sonne, Wind und Wärme* 2010 *(18/2010)*: 60–64.

[17] Fuchs B, Hofbeck K. Vakuumgedämmter Multifunktions-Wärmespeicher Sengenthal. In: M. Rommel, editor. *21. Symposium Thermische Solarenergie*. Regensburg: OTTI 2011.