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Preparation and characterization of vacuum insulation panels with super-stratified glass fiber core material

Zhou Chen [a, b, c], Zhaofeng Chen [a, *], Zhaogang Yang [b], Jiaming Hu [b], Yong Yang [a], Lingqian Chang [b], L. James Lee [b], Tengzhou Xu [a]

[a] College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
[b] Nanoscale Science and Engineering Center, The Ohio State University, Columbus, OH 43210, United States
[c] Suzhou V. I. P. New Material Co., Ltd, Hong Da Fang Yuan Group, Suzhou 215400, PR China

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ABSTRACT

VIPs (vacuum insulation panels) with super-stratified glass fiber core material were prepared by CSB (centrifugal-spinneret-blow) process. The fiber orientation of the super-stratified glass fiber core material was concentrated in the X–Z plane which was perpendicular to the heat transfer direction. The initial thermal conductivity of this novel VIPs was only 1.25 mW/(m K) which performs up to two times more thermal insulation than conventional wet core material (2.62 mW/(m K)). The thermal conductivity of VIP with CSB-3 μm was significantly lower than that calculated from the theoretical curves with mean pore size of 10 μm. The results demonstrated that thermal conductivity of VIP with CSB-3 μm attained 1.25, 1.76, 2.04, 2.91, 3.45, 4.58, 9.16, 13.03 mW/(m K) under the pressure of 0.03, 0.06, 0.09, 0.3, 0.5, 0.9, 5 and 10 mbar, respectively. This is a great breakthrough to dramatically increase the service life-span of VIP with glass fiber core material. Their further advantages compared to conventional wet process are their lower energy consumption and cost.

1. Introduction

Energy and the environment are the largest problems and challenges to the whole world in the twenty-first century [1,2]. The world today relies on a large amount of fossil fuels to produce energy. The continued use of fossil fuels will strain our resources and produce large amounts of pollution, especially CO_2 emissions [3,4]. An effective power-saving technology will have a beneficial effect on controlling CO_2 emissions. VIP (vacuum insulation panel) has already been widely applied in many heat preservation fields due to its very low thermal conductivity allowing thin layers, such as insulating refrigerators, automatic vending machines, cold storages and building envelope [5,6]. VIP constituted by porous and bearing core materials, high quality barrier packaging material and getters has a dramatically low thermal conductivity, which is 5–10 times lower than that of conventional insulators like polyurethane foams and polystyrene [7–9]. 25% of the thermal energy can be saved without detracting from the effective volume of refrigerator when VIP partly replaces polyurethane foam as the heat-insulation layer [10]. As can be seen from Fig. 1, the annual energy consumption and CO_2 emissions can be reduced by 7.8 KWh/(m^2 a) and 1.56 kg CO_2/(m^2 a) respectively by reducing the average U-value and increasing the building energy conservation in accordance to the standards of UK [11,12]. Moreover, it is difficult to meet the level 5 of the Code for sustainable Homes standard (0.25 KWh/(m^2 a)) by using thick conventional insulation material in modern slim architecture. The improvement in thermal performance of conventional insulation material is restricted by the gaseous conduction of the internal porous structure. VIPs are promising insulation material [13] however the present application of VIPs has two main barriers: high cost and uncertainty over useful life time.

The role of core material is to provide the insulating and mechanical properties for VIP [14]. So core materials for VIP should have characteristics such as high porosity with small interlinking open cell structure, structural strength and stability. Several different materials are used as core materials in VIP, such as open-cell polymer foams, inorganic fibers and powders. Fig. 2 shows the thermal conductivity of different evacuated core materials as function of internal pressure [15]. The initial thermal conductivity of VIP can be as low as 2.2 mW/(m K) for glass fiber core material,

* Corresponding author. Tel.: +86 25 52112909; fax: +86 25 52112626.
E-mail address: zhaofeng_chen@163.com (Z. Chen).

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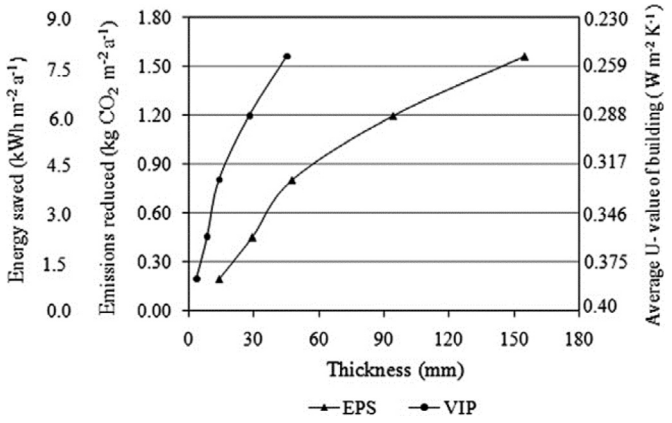

Fig. 1. Amount of energy saved and corresponding reduction in CO_2 emissions for varying thickness of EPS and VIP.

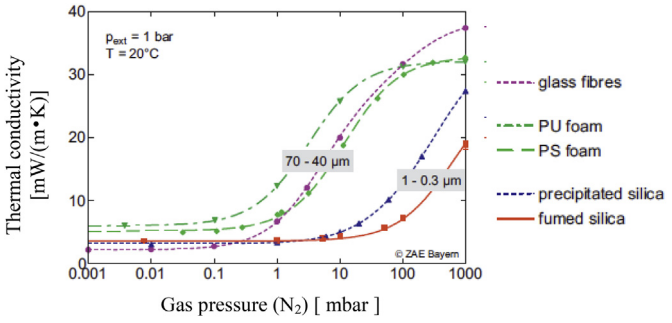

Fig. 2. Thermal conductivity of evacuated core materials as function of pressure.

3.6 mW/(m K) for nanoporous silica, and 5.2 mW/(m K) for organic foam [16–18]. Nanostructured powder of silica is the least sensitive material to internal gas pressure change. However it is not widely used due to high cost of production and elementary stage of development. The organic foam materials with better properties, such as fire resistant and flame-retardant characteristic, thermal insulation performance and stability, are continuously investigated [10,19]. Glass fiber core materials are mainly fabricated by wet papermaking process [20,21], which includes the following steps: beating slurry of glass fibers (i.e. flame attenuation glass fiber, centrifugal glass fiber or glass fiber chopped strand [22]); adjusting the pH value of slurry; vacuum dehydrating the slurry of glass fiber to form a wet-laid mat; drying the mat; finally cutting the mat to form glass fiber core material into a certain size [23,24]. The energy consumption and cost of production of wet papermaking process for core material account for more than 60% of the total consumption and cost of VIP. Glass fiber core material itself is relatively inexpensive and it has quite low effective thermal conductivity when evacuated, but the latter increases much faster with increasing pressure that of silica. Therefore, the glass fiber core material with lower energy consumption, lower cost of production, better performance, and more stability is needed for the future energy-saving technique.

In this paper, super-stratified glass fiber core material was directly prepared by CSB (centrifugal-spinneret-blow) process without wet environment. The effects of different diameters of glass fibers and the dimensionality of the stratified core material on the thermal performance of VIP were studied. The super-stratified microstructure was manifested by a base thermal conductivity of 1.25 mW/(m K). The initial thermal conductivity and aging performance of VIPs with super-stratified glass fiber core material were two times more than the conventional wet core material. Moreover, based on the energy price in Suzhou, VIPs with super-stratified

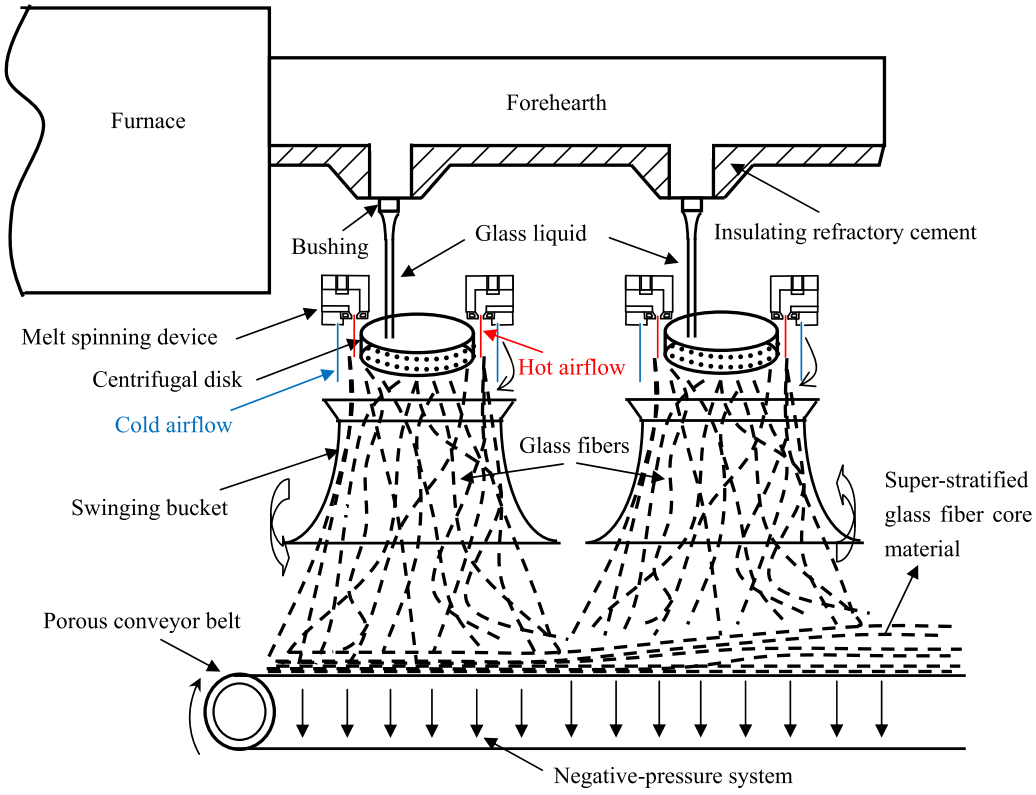

Fig. 3. The schematic of CSB process.