CHEMICAL ENGINEERING TRANSACTIONS

VOL. 55, 2016

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-46-4; **ISSN** 2283-9216

DOI: 10.3303/CET1655052

Application of SiO_2 Aerogel Material in Building Energy Saving Technology

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SiO_2 aerogel is a three-dimensional network structure solid materials, with the characteristics of low density, low thermal conductivity, high light transmittance, high porosity, high specific surface area and so on, but also has the excellent performance of fireproof and waterproof. It is a rare light, environmental protection, multifunctional material, which has great application prospects in the broad field of building thermal insulation. With the objective of building energy saving, this paper briefly describes the research on SiO_2 aerogels, discusses the possibility of large-scale production from preparation of diverse raw materials, raw materials and drying cost reduction and so on, focuses on the application progress in building insulation of SiO_2 aerogel glass and SiO_2 aerogel thermal insulation coatings; then, from the point of view of the excellent characteristics, this paper presents the application of a SiO_2 aerogel material in building energy saving technology, and from the SiO_2 aerogel materials in thermal insulation, waterproof, fireproof and simplifying the construction process and other advantages, constructs the application system that SiO_2 aerogel materials replace the current thermal insulation material in building energy saving. At last, it makes a conclusion and expectation of the SiO_2 aerogel materials application prospect in building thermal insulation.

1. Introduction

SiO_2 aerogel, as a kind of amorphous nano-porous material, its structure is controllable and it has continuous three-dimensional network structure. And the density is adjustable in 3-500mg / cm3, which is a kind of solid material with the world's lowest density. Its porosity is 80% ~ 99.8%, the pore size is in the range of 1 ~ 100nm, and the specific surface area can be as high as 1000m2/ g. Due to unique nano-porous structure, its thermal conductivity is very low (at ambient temperature, the thermal conductivity is low as 0.017W/ (m K)), which is the solid materials with the lowest heat conductivity at present (Hayase et al., 2014). Since that the structure unit of aerogel frame is smaller than that of the visible light, it also has better transmittance performance. At the same time, it is an inorganic material that has no burning or flame retardant effect, and has wide application prospect in the field of thermal insulation. In recent years, the research of SiO_2 aerogel is more and more widely, and in the improvement of mechanical properties, micro structure control, reducing the cost and improving the weather ability and thermal properties, it has made a series of significant progress.

As building energy efficiency requirements improve and the energy-saving technologies develop, building thermal insulation materials also develop to light, multi-functional and energy-saving environmental protection direction. In recent years, SiO_2 aerogel, as the new type of nano light, multifunctional, and environmental protection material, with its unique properties (low density, high specific surface area, low thermal conductivity and high optical transmittance etc.) has aroused more and more attention. Especially as an efficient thermal insulation material, it has become a hot research topic; it is light, fire resistant, transparent and heat insulating and environmental protecting, and compared with the traditional thermal insulation materials, it has incomparable advantages (Hurwitz et al., 2012). Therefore, it has great practical significance to develop the application of SiO_2 aerogel material in building energy conservation. In this paper, according to the unique properties of SiO_2 aerogels, comprehensively studying the SiO_2 aerogel materials at home and abroad in the building thermal insulation, proposes the application prospect of SiO_2 aerogel material in building energy saving technology.

Please cite this article as: Yu Z., Liang D.X., 2016, Application of sio2 aerogel material in building energy saving technology, Chemical Engineering Transactions, 55, 307-312 DOI:10.3303/CET1655052

2. SiO_2 aerogel material properties

Slender Nano network structure makes the $SiO_2$2 aerogel has very low solid and gas thermal conductivity. However, pure SiO_2 aerogel is almost through of the infrared radiation with band of 2 ~ 8μm. Iin the condition of high temperature, thermal radiation energy of this band will be almost all through the aerogel, resulting in thermal conductivity of SiO_2 aerogel rising sharply. In order to reduce the radiation thermal conductivity, we need to composite the light-screening agent that can absorb or scatter the infrared light in the aerogel.
The light-screening agent used mainly include: carbon, titanium dioxide (TiO_2) and potassium titanate whalebone etc. Te-Yu Wei and so on doped carbon nanofibers in aerogel, to achieve SiO_2 aerogel at 500 DEG C, and thermal conductivity of 0.050 W / m * K. Dmitry V. Fo-mitchev doped TiO_2, Zr SiO_4 and so on light-screening agents in sol-gel process, to make SiO_2 aerogel insulation performance improved by 40% - 60% than the traditional thermal insulation materials (Jin et al., 2015). Young-Geun Kwon et al. prepared SiO_2 aerogel doped with TiO_2 powder, to make it and the thermal conductivity at room temperature 400 DEG C to respectively reduce to as low as 0. 0136 W/m·K and 0. 0284 W / m·K.
The results show that the aerogel prepared by the two step method is better than that by the one-step method. And later, Cao and Hunt et al. Also proved this prediction. By reducing the concentration of water and the response temperature, it can also improve the transparency of aerogel. By adding suitable additives and using different drying and processing conditions, the aerogel block has different light scattering, which affects its optical properties. Some experts also introduced dimethylformamide (DMF) in the sol-gel process, to prepare aerogel with refractive index greater than 1.03 (Maleki et al., 2014). In addition, the aerogel obtained by CO_2 drying is more transparent than that of ethanol drying. The heat treatment of aerogel was carried out to remove water and organic matter, conducive to enhance its light transmittance.
To sum up, to improve the optical properties of aerogels, the appropriate precursor and sol-gel parameters should be selected. And the appropriate additives and proper drying methods can be used to reduce the gel matrix particles size and improve Its structure uniformity.

3. Application of thermal insulation in building

The application of SiO_2 aerogel in building insulation is mainly based on its low density, thermal insulation, flame retardance, high light transmittance and other characteristics. At present, the application form includes SiO_2 aerogel glass, SiO_2 aerogel insulation coating, SiO_2 aerogel fibre composite material and SiO_2 aerogel concrete and mortar.

3.1 SiO_2 aerogel material

SiO_2 aerogel is a material has two characteristics (low thermal conductivity and high optical transmittance) at the same time, especially with high light transmittance, so it can be used in architectural glass. It can not only reduce the outdoor heat to diffuse to the indoor, but also can prevent the indoor heat transferring to the outdoor, playing the role of heat preservation and insulation, but also not affecting the indoor lighting. The present research shows that there are two main ways to apply SiO2 aerogel to glass: one is to make it in the interlayer of the two glasses, and the other is to coat in the outside of the common glasses.
This kind of glass is currently researched more in foreign countries, while rarely reported in domestic. At first, Jensen K I let the monolithic silicon aerogel density of 150 kg /m3, 18mm thickness sandwiched between two pieces of 4 mm glasses, to make 1 m * 1 m windows, and eventually measure the made glass and the overall heat transfer coefficient 0.52 and 0.57 W/ (m2·K) (Muller et al., 2015). Schultz J M, on the basis of it, made great improvement, using vacuum splint form, the aerogel was first made into flat, then clipped into the middle of the two pieces of glasses, made to glasses with the thickness of 15 mm, and area of 55 cm * 55 cm, and carried out middle vacuum; in the meanwhile, the sealing ring was improved, and for the aerogel glass prepared by this method, the solar transmittance is 76%, the center heat loss coefficient of the glass is 0.66 W/ (m2·K). Later, Reim and other scholars made the aerogel particles filled into the glass, and the aerogel glass transmittance is 88%, and heat transfer coefficient is 0.4 W/ (m2·K), greatly improving its performance (Shi et al.,2013). This method has the advantage of aerogel sandwiched between two pieces of glass can avoid contact with water in the air, resulting in thermal conductivity increasing, but in the actual application usage, the gel is larger, and the cost is higher.
Kim and so on scholars added a layer of SiO_2 aerogel film on the glass surface by atmospheric pressure drying method. When the film thickness is 100μm, the transmittance of glass is more than 90%, and the thermal conductivity is 0.016 W/(m2·K). Coated glass can greatly reduce the thermal conductivity of glass, but it is directly contacted with air, exposure in the sun for a long time. It may cause damage to the insulation film and reduce the thermal insulation ability, but the coated glass, relative to the laminated glass, is low in cost.

3.2 SiO_2 aerogel insulation coating material

SiO_2 aerogel powder can also be added into the coating as a filler, made of SiO_2 aerogel insulation coating, which played a thermal insulation role in the building. Wang Demin regared the SiO_2 aerogel as functional filler to prepare heat insulation coating, and when SiO_2 aerogel coating accounted for 1% of the total mass of the coating, measured the glass plate temperature difference was about 9 DEG, and at that time, the insulation effect is the best (Siligardi et al., 2016). On this basis, Lu Bin and so on taking acrylic resin as film forming material, firstly modified SiO_2 aerogel and prepared the slurry, and made transparent insulation coating with additives and coated on the glass. The results showed that: when the film thickness is 20μm, the maximum film temperature difference reaches 14 DEG, and the insulation effect gets further promotion. Ibrahim M applied the SiO_2 aerogel insulation coating to the wall. From the heat attenuation coefficient, energy consumption index, and thermal comfort, taking simulation and actual measurement results as the basis, finally drew the conclusion that (Sun et al., 2015): in the continuous heating condition, when the coating is coated in the middle wall and the outer wall, the energy consumption is the lowest; in the intermittent heating and no heating conditions, when the coating is coated on the inner walls, the comfort is the best; the thermal insulation properties of SiO_2 aerogel insulation coating has good effect than other materials.

4. Application in building insulation system

To sum up, summarize the application progress of SiO_2 aerogel materials in recent years, it is not difficult to find that its application has irreplaceable advantages in the field of building. With light weight, it can effectively reduce the burden of the weight on the building itself (Wu et al., 2013); with effective thermal insulation and refractory, under the premise of the excellent heat insulation performance, it has both refractory performance, and it can replace the extruded polystyrene board, rock wool and other flammable materials currently used in the building; with environmental protection, it can minimize the various pollutions generated, and reduce the pollution to the natural environment and damage to human body. To this end, from the advantages of SiO_2 aerogel material, design a building envelope insulation system based on SiO_2 aerogel, and the specific assumptions is shown in figure 1.

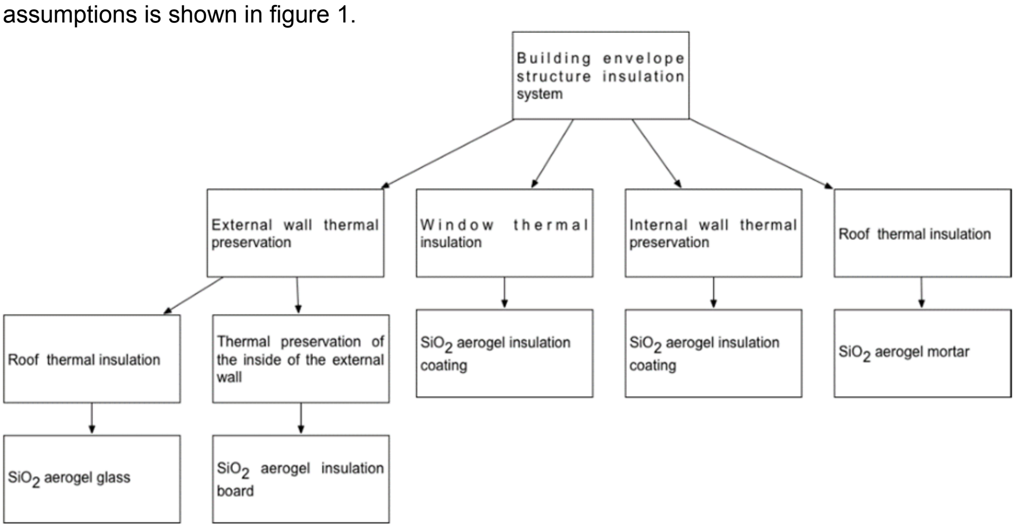

Figure 1: Insulation system of building envelope based on SiO2 aerogel material

In the building envelope structure, the wall occupies the largest area, and accounts for about 30% in the building energy consumption, so the insulation of the external wall is the focus of building energy saving. External wall insulation can be divided into: external wall outside insulation and external wall inside insulation. At present, in building external wall insulation, basically only carries out external insulation, while rarely carries out the inside insulation. The external insulation materials mainly adopt extruded polystyrene insulation board and EPS etc. These materials, as external wall insulation materials, is complicated in construction. In addition, from the structure layer→adhesive layer→leveling layer→wiping layer→insulation layer→the protective layer (Xie et al., 2014), the construction process is of variety. Although the insulation performance is good, it is flammable. In case of fire, burning will produce toxic fumes and cause great influence on the buildings and human body.

As a result, from the perspective of energy saving and environmental protection, in the perspective of building external wall insulation, plan to adopt SiO_2 aerogel insulation coating, which not only has excellent thermal insulation performance, but also has high temperature resistance, capable of effectively weakening the influence of solar radiation on the internal temperature of the building; and the construction is convenient, directly painted on the wall, which reduces lots of construction processes. Ibrahim M has been applied it to the wall and compared with other materials, providing reference for the application of SiO_2 aerogel insulation coatings. In the external wall insulation, adopt the scaled-production SiO_2 aerogel insulation board in the market, which is commercially available in Nano in Zhejiang and Alison companies in Guangdong (Xu et al., 2015). Its thermal conductivity is basically in 0.020 W / (m2·K), having good insulation properties, and it can withstand more than 400 DEG C high temperature. It not only effectively prevents the indoor heat spread to the outside, play the role of heat preservation, but also has the effect of flame retardant.

5. Results

5.1 Overall transmittance of aerogel

Because of its ultra-low thermal coefficient, SiO_2 aerogel thermal insulation materials have a good thermal insulation effect. Because the SiO_2 aerogel thermal material has a good light transmission performance, SiO_2 aerogel thermal insulation materials has a huge application prospects in the building thermal insulation. Recently, the application of aerogel has been well developed in super-insulating energy-saving glass due to its extremely low thermal conductivity and high transmittance. It has become a promising energy-saving material [56].The experimentally prepared SiO_2 aerogel thermal insulation material has the same performance, that is, the ultra-low thermal conductivity and high light transmittance. SiO_2 aerogel thermal insulation material has good transparency, and it can be used in architectural glass to achieve better lighting performance requirements.

The SiO_2 aerogel thermal insulation material was measured by the visible light transmittance and the shading coefficient of the building glass. The results showed that the aerogel transmittance was 53% and the total sunlight transmittance was 69%. The shading coefficient is 0.78, with high solar transmittance. The transmittance curve shown is in Figure 2.

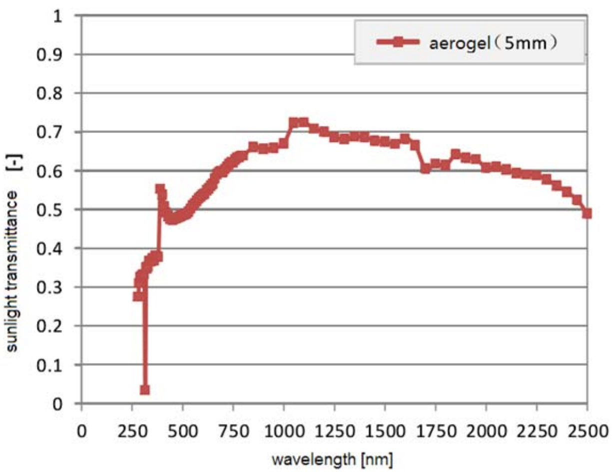

Figure 2: Transmittance performance curve of the SiO2 aerogel

5.2 The production and transmission and thermal insulation of aerogel glass

We used the atmospheric drying sol-gel method to prepare a block-shaped SiO_2 aerogel. The thickness of the aerogel was 5mm. The aerogel was filled into the center of two ordinary glasses with thickness of 5mm. All round of the airgel was sealed up by the foam to prevent sliding, and because the foam was soft, it can prevent the glass to crush the aerogel. Finally, a rubber was used to bind the laminated glass to be detected. The prepared aerogel laminated glass is 50x50x5mm3.

The properties of the aerogel glass at the five-pointed star in Figure 3 are the data calculated by Schultz et al. of the HILIT / HILIT + project in Denmark. The aerogel glass has been successfully prepared and the thickness of aerogel is 13.55mm, thermal conductivity is 0.017W / (m · k). The two glass are ordinary flat glass with 4mm thick, the thermal transfer coefficient of the aerogel laminated glass is 0.66W / (m2·k). The total sunlight transmittance is 76% ~ 80%. When the aerogel thickness is 20mm, the thermal transfer coefficient of the aerogel laminated glass can reach 0.50W (m2 ·k), and the total sunlight transmittance is still up to about 75%. Based on the thermal conductivity coefficient of the prepared aerogel and the total sunlight transmittance of the aerogel laminated glass, we can calculate, combined with the data in 3, the thermal transfer of the aerogel laminated glass made in the experiment was about 1.2W (m2 ·k).

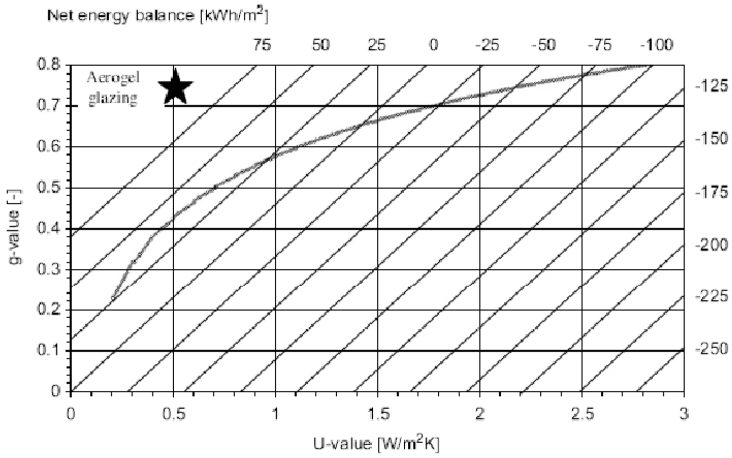

Figure 3: The performance of aerogel glazing on project HILIT/HILIT+in Denmark

The transmittance of the aerogel, the glass and the laminated glass is measured by the visible light transmittance of the architectural glass and the shading coefficient instrument. The sunlight transmittance curve is shown in Figure 4. As can be seen from Table 1, the visible light transmittance of 5mm thick ordinary flat glass is 89%, the sunlight total transmittance is 82%. The visible light transmittance of double layer 5mm thick ordinary glass is 77%, and the sunlight total transmittance is 69%, the shading coefficient is 0.78. After it combined with two ordinary flat glasses and composed of laminated glass, the visible light transmittance was 43%, the total sunlight transmittance was 58%, the shading coefficient was 0.66, and lowered about 19% and 16% respectively compared with the single-layer aerogel, and the shading coefficient lowered about 15%. The results showed that the aerogel glass had better shading effect when it had certain solar transmittance. The thermal transfer coefficient of aerogel laminated glass reduced by about 80% compared to ordinary flat glass, so the aerogel glass with such low thermal transfer coefficient used in northern heating season can achieve a good energy saving effect. Therefore, the study of high performance, good air permeability of aerogel and its application in building energy efficiency is the future development trend.

Table 1: Optical and thermal parameters of aerogel glass

Type	Thickness (mm)	Thermal conductivity coefficient W/(m`k)	Visible light transmittance tv	total sunlight transmittance gg	Shading coefficient SC	Thermal transfer coefficient Ug[W/(m2`k)
aerogel	5	0.018	0.53	0.69	0.78	
Single-layer ordinary glass	5	0.75	0.89	0.82	0.92	5.7
Doubt-layer ordinary glass	5+5	0.75	0.77	0.71	0.80	5.5
Ordinary glass+aerogel+ordinary glass	5+5+5		0.43	0.58	0.66	1.2

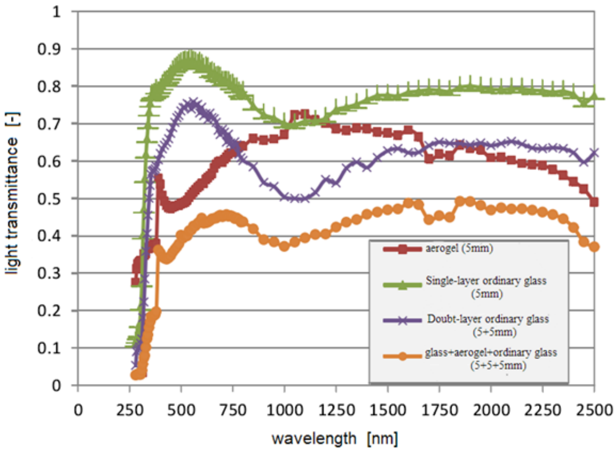

Figure 4: Transmission performance curve of aerogel and glass

6. Conclusion

With the deepening of the research, SiO2 aerogel material is bound to replace the insulation materials in the current buildings, and usher its broad application prospects. Whereas, it still needs to make efforts from the following aspects.

1) As rice husk ash and so on cheap silicon sources occur, it promotes the cost reduction of the preparation of SiO_2 aerogel materials, to lay the foundation for the popularization and application. But the purification problem remains to be solved, and the large-scale industrial production needs to be improved.

2) The application of atmospheric drying method reduces the cost of drying equipment for the preparation of SiO_2 aerogels, but to obtain ultra-low density and high-performance SiO_2 aerogel, the drying process is yet to be optimized.

3) On the basis of cost reductionof SiO_2 aerogel, the cost of SiO_2 aerogel material should be reduced, and the construction technology should be further improved.

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