A New Method for Measuring the Thermal Insulation Properties of Fibrous Silica Aerogel Composite

Z. Talebi Mazraeh-shahi\textsuperscript{a,b,*}, A. Mousavi Shoushtari\textsuperscript{b}, A. R. Bahramian\textsuperscript{c}

\textsuperscript{a}Department of Textile Engineering, Isfahan University of Technology, Isfahan, Iran
\textsuperscript{b}Department of Textile Engineering, Amirkabir University of Technology, Hafez Ave, Tehran, Iran
\textsuperscript{c}Polymer Engineering Department, Faculty of Chemical Engineering, Tarbiat Modares University, Tehran, Iran

Abstract

In this work, the thermal diffusivity and thermal conductivity of nonwoven fabric and silica aerogel/nonwoven fabric composite was determined by a new method for the investigation and comparing the thermal insulation properties of them. The thermal diffusivity of the neat nonwoven fabric and its silica aerogel composite was calculated from the temperature distributions curves and the numerical solution of the heat transfer equations. The temperature distributions curve was obtained using Marsh cooling method in which the cooling rate of a fluid such as water or oil inside a hot body wrapped with fibrous sample could be measured. The results showed that the presence of silica aerogel in the matrix of nonwoven fabric led to significant decrease in the thermal diffusivity of the composite ($1.3 \times 10^{-7}$ m$^2$/s) compared to the neat nonwoven fabric ($2.6 \times 10^{-7}$ m$^2$/s).

1. Introduction

Silica aerogel with outstanding properties namely high porosity, low density, large surface area and very low thermal conductivity has been found usage in widespread applications in recent years. However, its high porosity leads to the brittleness and low mechanical properties of silica aerogels which has restricted the commercial use of these materials, Shi et al. (2006), Zhang et al. (2009), Ge et al. (2009), Leventis (2007).
In recent years, the fibrous materials as a secondary reinforcement have been used to reinforce the brittle aerogel network, Obrey et al. (2011), Fidalgo et al. (2013), Liu et al. (2012). These flexible aerogel blankets have been made by using the silica aerogel lies onto a fibrous material such as nonwoven fabrics and improved mechanical properties could be resulted, Zhang et al. (2006), Oh et al. (2009).

In the most of works, flexible aerogel blankets have been fabricated using a fiber glass batting as the fibrous material for thermal insulation applications. Also, the thermal conductivity has been commonly measured for investigation of their thermal insulation properties. The silica aerogel/PET nonwoven blanket with environmentally friendly properties has been studied recently by Talebi et al. (2014). They prepared a PET nonwoven/silica aerogel composite via a two-step catalyzed sol-gel followed by ambient pressure drying conditions.

In this work, a new method is applied for measuring the thermal diffusivity and thermal conductivity of fibrous materials and their aerogel composite.

### Nomenclature

| Abbreviation | Description |
|--------------|-------------|
| TEOS | Tetraethoxysilane |
| TMCS | Trimethylchlorosilane |

### 2. Experimental

Tetraethoxysilane (TEOS) and Trimethylchlorosilane (TMCS) were given from Merck Co. The solvents were supplied from Scharlau Co. PET nonwoven fabric was supplied from Bibaft Co., Iran.

A PET nonwoven felt and TEOS as precursor for silica sol synthesis were used for preparation of fibrous silica aerogel composite, Talebi et al. (2013). The silica aerogel/PET nonwoven composites were obtained successfully via a two-step sol-gel process under ambient pressure drying conditions according to our previous work, Talebi et al. (2014). PET nonwoven felt and two composite samples are denoted as B-PET and CA-V respectively which V represents the volume ratio of initial sol mixture to the nonwoven felt in composite samples.

### 3. Results and Discussion

The heat transfer through fibrous materials is a very complex phenomena involved the conduction and radiation heat transfer modes and the radiation heat transfer mode can be ignored in low temperature. The conduction heat transfer contains solid conduction through fibers and gas conduction in the micro pores among the fibers according to equation (1). Gas conduction is the main heat transfer mode in fibrous materials with high porosity which is strongly affected by the porosity and pore size of fibrous mat and the gas mean free path, Daryabeigi (1999).

\[
\lambda = f (f^2 \lambda_f^* + (1-f) \lambda_g^*)
\]

Where $\lambda$ is the thermal conductivity, $f$ is the fiber volume fraction, $\lambda_f^*$ is the thermal conductivity of the fiber parent material and $\lambda_g^*$ is the gas thermal conductivity.

Silica aerogel due to its high porosity and very low conductivity (10-15 mW/mK) has been used as one of the best thermal insulation materials, Pierre and Pajonk (2002). The mesopores of silica aerogel are smaller than mean free path of the air molecules (70 nm) results in very low gas conductivity of aerogel. The filling of the micro pores of fibrous felt with silica aerogel leads to decrease in the gaseous thermal conductivity and the improved thermal insulation properties of the silica aerogel/nonwoven blanket is resulted, Kim et al. (2008).

#### 3.1 Measurement of thermal insulation properties

In this work, the thermal diffusivity and thermal conductivity of fibrous samples were determined by a new method. The temperature distributions curve (temperature versus time curve) was obtained using Marsh cooling.
method in which a cooling rate of a fluid such as water or oil inside a hot body wrapped with fibrous sample was measured, Debnat and Madhusoothanan (2010). In this research, a brass cylinder (10 cm length, 3 cm external diameter and 2 mm thickness) was used as the hot body (fig. 1). The brass cylinder was filled with silicon oil and closed one end by a crock then heated to about 150 °C. Then the cooling rate of silicon oil was measured in different times and its temperature distributions curve was obtained for all fibrous samples (fig. 2).

![Fig. 1. (a) brass cylinder; (b) brass cylinder wrapped with fibrous sample.](image)

The thermal diffusivity of the fibrous samples was calculated from the numerical solution of the heat transfer equations and temperature distributions curve according to Bahramian et al. work, Bahramian and Kokabi (2009). Also, thermal conductivity could be calculated using equation (2):

\[ \lambda = \alpha C_p \rho \]  

(2)

Where \( \alpha \) is the thermal diffusivity, \( C_p \) is the heat capacity and \( \rho \) is the density of samples, Katti et al. (2006).

![Fig. 2. Temperature distributions curves of fibrous samples.](image)

The thermal diffusivity and thermal conductivity of the neat PET nonwoven and silica aerogel/PET nonwoven composite samples are given in table 1. The results demonstrate that silica aerogel gives rise the improvement of the thermal insulation properties of fibrous composite samples. However, the thermal diffusivity and thermal
conductivity of the silica aerogel composite samples decreases with decreasing the volume ratio of initial sol mixture to the nonwoven felt (silica aerogel content).

Table 1. Thermal insulation properties of the neat PET nonwoven and silica aerogel/PET nonwoven composites.

| samples   | V (sol volume ratio) | ρ (g/cm³) | C_p (J/kg.K) | α × 10⁷ (m²/s) | K (mW/m.K) |
|-----------|----------------------|-----------|--------------|----------------|------------|
| B-PET     | 0                    | 99        | 1200         | 2.6            | 30.8       |
| CA-1.92   | 1.92                 | 200       | 811          | 1.3            | 21.1       |
| CA-2.4    | 2.4                  | 267       | 804          | 1.58           | 32.5       |

4. Conclusions

In this work, a new method is applied for measuring the thermal diffusivity and thermal conductivity of fibrous materials and their aerogel composite. The thermal diffusivity was calculated from the temperature distributions curves and the numerical solution of the heat transfer equations. Also, the thermal conductivity of samples calculated using the thermal diffusivity. The silica aerogel composite exhibited the noticeable decrease in the thermal diffusivity compared to the neat nonwoven fabric. The thermal diffusivity and thermal conductivity of the silica aerogel composite samples decreases with decreasing the silica aerogel content.

References

Bahramian, A.R., Kokabi M., 2009. Ablation mechanism of polymer layered silicate nanocomposite heat shield. Journal of Hazardous Materials 166, 445-454.

Daryabeigi, K., 1999. Analysis and Testing of High Temperature Fibrous Insulation for Reusable Launch Vehicles. 37th AIAA Aerospace Sciences Meeting and Exhibit. USA, AIAA 99-1044.

Debnat, S., Madhusoothanan, M., 2010. Thermal insulation, compression and air permeability of polyester needle-punched nonwoven. Indian Journal of Fibre & Textile Research 35, 38 (2010).

Fidalgo, A., Paulo, J., Farinha, S., Martinho, J.M.G., Ilharco, L.M., 2013. Flexible hybrid aerogels prepared under subcritical conditions. Journal of Materials Chemistry A 1, 12044-12052.

Ge, D., Yang, L., Li, Y., Zhao, J., 2009. Hydrophobic and thermal insulation properties of silica aerogel/epoxy composite, Journal of Non-Crystalline Solids 355, 2610–2615.

Katti, A., Shimp, N., Roy, S., Lu, H., Fabrizio, E.F., Dass, A., Capadona, L.A., Leventis, N., 2006. Chemical, Physical, and Mechanical Characterization of Isocyanate Cross-linked Amine-Modified Silica Aerogels. Chemistry of Materials 18, 285-296.

Kim, C.Y., Lee, J.K., Kim, B.L., 2008. Synthesis and pore analysis of aerogel–glass fiber composites by ambient drying method. Colloids and Surfaces A 313–314, 179-182.

Liu, J., Wang, X., Shi, F., Luo, J., 2012. Preparation and characterization of silica aerogels/glass wool composites. Advances in Materials Research 534, 106-109.

Maleki, H., Durães, L., Portugal, A., 2014. An overview on silica aerogels synthesis and different mechanical reinforcing strategies. Journal of Non-Crystalline Solids 385, 55-74.

Obrey, K.A.D., Wilson, K.V., Loy, D.A., 2011. Enhancing mechanical properties of silica aerogels. Journal of Non-Crystalline Solids 357, 3435–3441.

Oh, K.W., Kim, D.K, Kim, S.H., 2009. Ultra-porous Flexible PET/Aerogel Blanket for Sound Absorption and Thermal Insulation. Fibers and Polymers 10, 731-737.

Pierre, A.C., Pajonk, G.M., 2002. Chemistry of Aerogels and Their Applications. Chemical Reviews 102, 4243–4265.

Shi, F., Wang, L., Liu, J., 2006. Synthesis and characterization of silica aerogels by a novel fast ambient pressure drying process. Materials Letters 60, 3718–3722.

Talebi Mazraeh-shahi, Z., Mousavi Shoushtari, A., Abdouss, M., Bahramian, A.R., 2013. Relationship analysis of processing parameters with micro and macrostructure of silica aerogel dried at ambient pressure. Journal of Non-Crystalline Solids 376, 30–37.

Talebi Mazraeh-shahi, Z., Mousavi Shoushtari, A., Bahramian, A.R., Abdouss, M., 2014. Synthesis, Structure and Thermal Protective Behavior of Silica Aerogel/PET Nonwoven Fiber Composite. Fibers and Polymers 15, 2154-2159.

Zhang, H.X., He, X.D., He, F., 2009. Microstructural characterization and properties of ambient-dried SiO2 matrix aerogel doped with opacified TiO2 powder. Journal of Alloys and Compounds 469, 366–369.
Zhang, Z., Shen, J., Ni, X., Wu, G., Zhou, B., Yang, M., Gu, X., Qian, M., Wu, Y., 2006. Hydrophobic Silica Aerogels Strengthened with Nonwoven Fibers. Journal of Macromolecular Science, Part A: Pure and Applied Chemistry 43, 1663-1670.