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The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2019; 8(2): 329-332

www.thepharmajournal.com
Received: 09-12-2018
Accepted: 13-01-2019

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Use of aerogel in textile and apparel industry

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Abstract
Aerogels are highly porous materials with extreme properties it was in 1930 that Kistler invented the first process for making such a highly porous inorganic silica product. (Venkaterman, *et al*. 2015). It consists of more than 96% air and remaining 4% is a wispy matrix of silicon dioxide. Aerogel are mainly three types i.e. silica, carbon and metal oxides. Silica aerogel used for insulation, carbon aerogels useful for super capacitors, fuel cells and desalination systems, metal oxides aerogel are also used in the production of explosives and carbon nanotubes. The unique properties of aerogels are extremely useful for designing flexible and lightweight insulation materials. "Aerogel is an amazing insulator; it has to be since NASA uses it in outer space where the temperature is only 2 degrees above absolute zero" (Stella, 2016) [10]. The mechanical and thermal properties of the product may be varied based upon the choice of reinforcing fibres, the aerogel matrix, and pacifications additives included in the composite. Benefits of application of aerogel product i.e. labour costs and maintenance costs will be decreased due to self-cleaning super hydrophobic surface of the elements and improved human comfort due to moisture management. It can be used for the development of a wide varieties of products in field of textile arogel used in antibacterial textiles, medical textile, insulating textiles, fire retardant textiles, intelligent textiles, clothing & apparels, footwear, gloves, green building and other thermal insulating products also discussed in this article.

Keywords: Types, manufacturing process, textiles application, benefits, future of aerogel

Introduction
According to IUPAC, Aerogel is a gel comprising a micro porous solid in which the dispersed phase is a gas. It consists of more than 96% air. The remaining 4% is a wispy matrix of silicon dioxide (Fig. 1). Consequently, it is one of the lowest density solids ever conceived. Aerogels are also known as frozen smoke, solid smoke, solid air, or blue smoke.

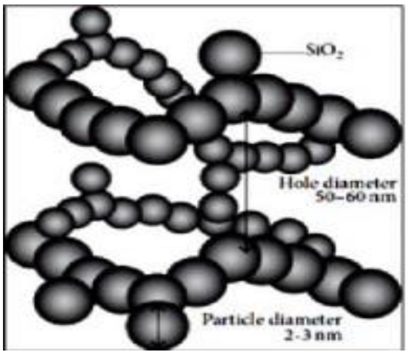

Fig 1: Structure of silica aerogel

Structure of aerogels: (i) Gel-like structure on nano scale coherent skeletons and pores (ii) Hierarchical and fractal microstructure (iii) Macroscopic monolith (iv) Randomly cross-linked network (v) Non-crystalline. Characterized as low-density solids with a low optical index of refraction, low thermal conductivity, low speed of sound through the material, a high surface area, and a low dielectric constant.

Method of manufacturing
By sol gel process [A Gel (Three-Dimensional, Highly Porous Solid Network) that is derived from a Sol-(Colloidal Suspension of Particles) and By supercritical drying process is used for making aerogels because Supercritical drying is the more expensive and risky step in the process of making aerogels.

Manufacturing process

Aerogels are produced through the creation of gelatinous structures and then removal of all liquid without allowing any shrinkage. It is then packed with microscopic insulative air pockets of silica, alumina, carbon or other such materials with diameters of less than 100 nanometers that make it impossible for most gas molecules, including air, to pass through, resulting in virtually zero heat loss.

Properties of aerogel

Table 1: General properties and value of aerogel

Sr. no	Property	Range
1.	Bulk density (g/cc)	0.003-0.500
2.	Porosity (%)	80-99.8
3.	Mean pore diameter(nm)	20-150
4.	Inner surface area (m2/g)	100-1600
5.	Refractive index	1.007-1.24
6.	Thermal conductivity (in air 300)(w/(mk)	0.017-0.021
7.	Modulus of elasticity (mpa)	0.002-100
8.	Sound velocity (m/s)	<20-800
9.	Dielectric constant (at 18-40 GHz)	1-2

(i) Ultra-low thermal conductivity
(ii) Ultra-low refractive index
(iii) Ultra-low dielectric constant
(iv) High surface area
(v) High refractive index, porosity

Aerogels are also extremely fragile. Similar in chemical structure to glass, though 1,000 times less dense, they are often prone to breaking when handling, seemingly their only drawback, aside from their cost. However, composite of aerogel with textiles offers the potential to improve the handling performance by way of increased flexibility. Rodie, 2013 [9]. Stated that aerogels developed in 1930s and first used as insulating materials in industrial and National Aeronautics and Space Administration (NASA) applications, outdoor apparel, footwear and other outdoor gear. The nano porous materials comprised an amorphous silica gel impregnated into a nonwoven flexible substrate. The resilient, thin chips thus produced are made up more than 90 percent of air; resist compression under load; and retain their thermal performance even when pressures as high as 50 pounds per square inch (psi) were applied. They found lowest thermal conductivity compared to foams, fiberglass and lofted polyester insulation.

Types of aerogel

Silica aerogels: Silica aerogels are ultra pure gels derived by hydrolysis-condensation reaction of silica alkoxide or salts. It is a glassy and lightweight material often used for insulation purpose. Silica aerogels are generally used for textile as compare to carbon and metal oxide aerogels.

Carbon aerogels: Carbon-based aerogels are black and feel like charcoal to touch and have high surface area. They are electrically conductive and this property make carbon aerogels useful for super capacitors, fuel cells and desalination systems.

Metal oxides aerogels: These are made from metal oxides (Iron, tin, copper, gold) and are used as catalysts for chemical transformations. They are also used in the production of explosives and carbon nano tubes, and can even be magnetic.

Applications of aerogels

In the 1990s, some of the main areas of applications of aerogel identified included:

- In textiles, Interior and exterior insulating plasters for breathable building envelopes and facades, Industrial insulation, Thermal insulation coatings for safe-to-touch surfaces, energy efficiency, prevention of corrosion under insulation (CUI), Thermal breaks, and Condensation control, Insulation packs for oil and gas subsea pipelines, Skylights, Cosmetics and nuclear weapons.

Application of aerogels in textiles

Aerogel can be used for the development of a wide variety of novel high-performance products.

Textile: Antibacterial, medical, insulating, fire retardant, intelligent and textile Composites, Clothing & apparels – Spacesuits, Jackets for protection from extreme cold weather conditions, Footwear, gloves, Green building, Packing materials and shipping containers, Other thermal insulating products

Antibacterial textiles: Aerogels can be used in textiles requiring antibacterial properties. Material with adaptive antibacterial killer based on sol/gels TiO_2, which remains active in wet state only. Mahltig *et al*. 2004 [8] investigated antibacterial effect by embedding the biocides in silica coatings. Biocides used in study were silver nitrate, colloidal Ag, (cetyl trimethyl ammonium bromide) CTAB, and octenidine. Their results showed biocidal additives Octenidine and CTAB exhibit high inhibition rate of more than 90% against the fungi Aspergillus niger after 4hr of leaching, whereas colloidal Ag treated samples without sol-gel have the lowest inhibition.

Medical textiles: The combination of biopolymers with siloxanes under mild chemical conditions has been used for the preparation of silica-biopolymer hybrids in the form of films for membranes or coatings. It has biodegradable, bioadhesive with multifunctional properties**.** These hybrid materials find application in the field of biocompatible materials, bone substituent's, cements for bone repair and reconstruction.

Insulating textiles: The unique properties of aerogels can be extremely useful for designing flexible and lightweight insulation materials from textiles. Fabrics containing Aerogels may ultimately be of interest to the automotive industry as well as in building and construction products such as composite blankets for energy conservation in buildings to prevent heat loss, gain solar heat, and for daylight harvesting by transmitting and diffusing natural light. The “pyrogel” insulation developed by Aspen Aerogel Inc. has been proven to be an effective underfoot barrier to extreme cold in the form of insoles for climbers on Mt Everest, where their light weight and flexibility are extremely useful. Fu. *et al*. 2012 [5]. Prepared and studied thermal performance of alumina aerogel insulation composites. The results showed, compared with silica aerogel, alumina aerogel can withstand even 1000℃ but still keeps the porous network. When alumina aerogel was introduced into the ceramic fiber, due to the excellent thermal resistance property of alumina aerogel, the thermal insulation property of composites was evidently improved.

Aerogels in intelligent textile: Aerogels can be used with smart textiles to design novel sol/gel products such as alumina silica piezoelectric aerogels in the field of energy harvesting carpets. These can convert the stresses acting upon it when people walk over it, in to usable form of energy to power a small battery; wall coverings and curtains which utilise the energy of wind to power an array of LEDs for indoor applications. Karadagli *et al.* 2012. conducted a research on synthesis and characterization of highly porous cellulose aerogels for textiles applications and presented the properties of ultra-light and porous cellulose aerogels in different forms: monoliths and fine spun fibers. The cellulose aerogel monoliths and fibers were prepared by dissolving microcrystalline cellulose (0.5-6 wt. %) in a hydrated calciumthiocyanate salt melt at 110 °C upon cooling the solution gels around 80 °C. Washing the wet gels and regeneration of the cellulose in an ethanol bath followed by drying in an autoclave yield aerogels.

Flame retardant textiles: Aerogels can also be used to impart flame retardant finishes to fabrics for eg. coatings of protective clothing using aero gels. Heat transfer by the gas phase could be avoided by evacuation. Evacuated Si-aerogel showed reduced thermal conductivity of one half. Aerogels can also be utilised for development of novel anti-wetting coatings on textiles such as silica-biopolymer coatings to render highly hydrophobic characteristics to the fabrics. Chunxin. 2016 [4]. Conducted a research aerogel-based fire protective clothing and analysed the insulation material and performance of the active fire protective clothing, and also analysed the application of aerogel in clothing as new nano insulating material. The results showed that the weight and the thickness of the fire protective clothing, in which the SiO2 aerogel composite was used, were proved to be lessened by more than 70% under the similar promised of thermal protective performance (Fig. 2).

Fig 2: Aerogel-based fire protective clothing

Aerogels In: clothing's, apparels, and footwear: The aerogel composite material consists of two phases. The first is a low-density aerogel matrix and the second is a reinforcing phase. This reinforcing phase consists primarily of fibres, preferably a combination of the batting and one or more fibrous materials of significantly different thickness, length, and/or aspect ratio. A preferred combination of a two fibrous material system is produced when a short, high aspect ratio micro fibre (one fibrous material) is dispersed throughout an aerogel matrix that penetrates a continuous lofty fibre batting (the second fibrous material). Such aerogel-based insulation materials can be used for insulation components in apparel and footwear applications.

Aerogels have from two to six times more insulating power than other commonly used materials. Mount Everest climbers have used aerogel insoles, as well as sleeping bags lined with the material The US company, Aerogels Inc., offers insulation components based on Aerotherm aerogel products for footwear as well as components for gloves and insulation panels for garments. Stella, 2016 [10]. Stated that "Aerogel is an amazing insulator; it has to be since NASA uses it in outer space where the temperature is only 2 degrees above absolute zero."

Footwears: Aerogel -In foot wears including ethylene vinyl acetate (EVA) molded and flat insoles, liners, strobe, uppers, toe cap, and other components. In order to maintain either stylish designs and/or functional performance in footwear applications, there is very little space available for insulation. The aerogel product Pyrogel® AR5401 (Aspen Aerogels Inc.), a carbon-filled aerogel, is upgrade the performance of their footwear and cold weather products, while increasing the freedom for design and the inclusion of other functional elements.

Zrim *et al*. 2015 [12] conducted a research on properties of laminated silica aerogel fibrous matting composites for footwear applications. They described lamination method of commercially produced silica aerogel composite and investigated its suitability for thermal insulation within protective footwear applications (Fig. 3) for severe cold and extreme high-altitude environments. A silica aerogel composite was used with a thickness of 2.7 mm and mass per unit area of 500 gm^{-2}. A solid 5 µm thick membrane was used, reinforced with an abrasive resistant polyester knitted fabric.

Fig 3: silica aerogel composite in footwear

Future of Aerogels

Although aerogel is expensive, researchers are still experimenting with ways to make it stronger, cheaper and less hazardous. Professor Nicholas Leventis from the Missouri University of Science announced that he had developed a method for making non-brittle aerogels. Despite some negatives, aerogels have the following possible applications: Insulating skylights, Non-deflatable (or "run-flat") tires, Aircraft structural components, Heat shields for spacecraft, Manufacturing methods for further process will improved and cost reduction to add, Development of new types of aerogel composites in clothing and footwear, Development of new methods to treat fabrics with aerogel particles to reduce fragility and sensitivity to moisture, Develop or update standards for thermal measurement in aerogel-based insulation materials used for textile applications, because existing standards do not address the necessary parameters

under extreme conditions.
Analysts forecast the global aerogel market to grow at a CAGR of 35.86% over the period 2014–2019. The high number of patents being filed for new uses of aerogel and the development of new aerogel-based products is expected to contribute to market growth in the coming years. Polym. Preprints 2011.52 (1) p.250.

Conclusions

Aerogels was in 1930 that Kistler invented the first process for making such a highly porous inorganic silica product.. It can used for the development of a wide varieties of products in field of textile. The unique properties of aerogels are extremely useful for designing flexible and lightweight insulation materials. The mechanical and thermal properties of the product may be varied based upon the choice of reinforcing fibres, the aerogel matrix, and pacifications additives included in the composite. Silica aerogel blankets made from silica aerogel integrated into nonwoven fabrics can reduce energy consumption from heating or cooling the interior of a fabric structure by 30%–70%, depending on the climate and is being used as the insulation, in the field of energy harvesting carpets which can convert the stresses acting upon it when people walk over it, in to usable form of energy to power a small battery and many more.

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