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EVALUATION OF EFFECTIVE THERMAL CONDUCTIVITY AND DEVELOP LIGHT WEIGHT AEROGEL FOR SPACE APPLICATION

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Abstract- *Aerogel is a synthetic porous ultralight material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density and low thermal conductivity Launching a heavy lift system into low Earth and geosynchronous orbits. By this study we can compare the merits of aerogel over Multi Layer Insulation(MLI).*

Keywords- *Aerogel, Aerogel blankets, thermal insulation,modelling*

I. INTRODUCTION

For obvious reasons, the demand for innovative energy-saving materials is growing. Although the building sector remains the main interested party for new energy-efficient materials, other applications are concerned as well. In space (full vacuum conditions, P < 10-5 mBar), for instance, the heat transfer occurs by solid conduction and/or by radiation only. Insulation is generally provided by Multi-Layer Insulation (MLI), based on a stack of multiple thin reflectors with very low infrared emissivity. MLI are presently the most efficient technical solution, with performances far above those of any other thermal insulation materials with comparable mass and envelope . However, when the pressure differs from zero, MLI performance decreases rapidly. The thermal conductivity of a typical MLI blanket may increase by two orders of magnitude between full vacuum conditions (in spacecraft thermal control conventionally defined as P < 10-5 mBar = 0.001 Pa) and a pressure of 1 mBar (100 Pa). For cargo modules or manned or unmanned compartments in ascent/(re-)entry vehicles or on Mars surface where an atmosphere is present, MLI becomes less efficient and alternative materials are needed.
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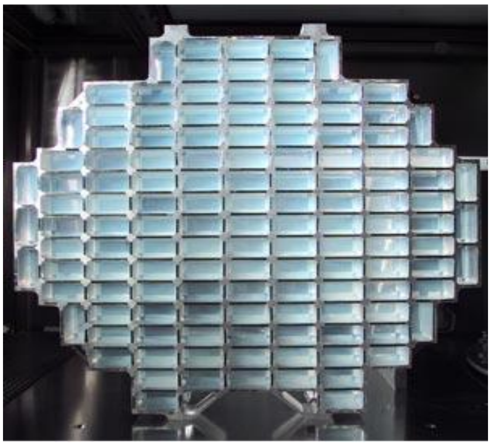
1.1. What is aerogel?

Aerogels are made from gels of various raw materials—including silica, alumina, polymers, or carbon-based material—that remove solvents using methods such as supercritical drying. Aerogels have been known for many years as the solids presenting the lowest thermal conductivity at ambient pressure ever measured , with conductivities as low as 0.012 W.m-1.K-1. Therefore, aerogels are very promising candidates to solve above-mentioned issues MLI face i.e. in environments where convection and gas conduction take place. In order to be used for space applications aerogels have additionally to present a low apparent density, be easy to handle and to shape. In this context, the aim of the present work was to develop new aerogel materials presenting a favorable compromise regarding thermal conductivity (< 0.03 W.m-1.K- 1) and apparent density (< 0.05 g.cm-3).Silica aerogels are the most widely known type of thermally insulating aerogels. Even so, theyare rather fragile materials, even if tuning their sol-gel synthesis parameters allows improving mechanical properties, like compressive strength, significantly .

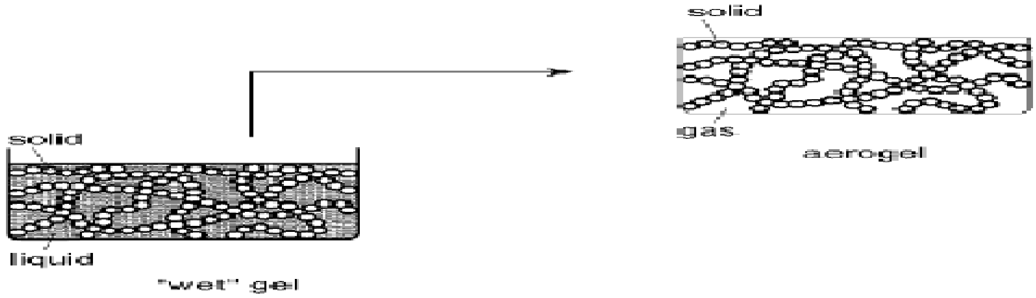
Several promising composites have already been developed and are presently commercialized (so-called silicabased blankets) but remain elements releasing much powder. Today, many studies are thus dedicated to reinforcing the mechanical properties of silica aerogels. One promising method currently studied involves via organic-inorganic hybridization, as organic aerogels are known to possess better mechanical properties than their silica counterparts . Various interpenetrated networks have been synthesized at lab-scale based, for instance, on coupling silica with polyurethane or with bisphenol . One of the main methods studied within the aerogel community for enhancing an aerogel's mechanical properties is based on cross linking (i.e. covalent coupling between organic and mineral matrices after chemical grafting of silica . However, this synthesis process involves several steps. Recently, research on “one-pot” processing methods has begun to emerge. Among the different studies on this topic, several focus on coupling silica with resorcinol-formaldehyde (RF).

Aerogels have extremely low thermal conductivity, high sound-insulating properties, small refractive indexes, and other properties that could not be realized in conventional solids.



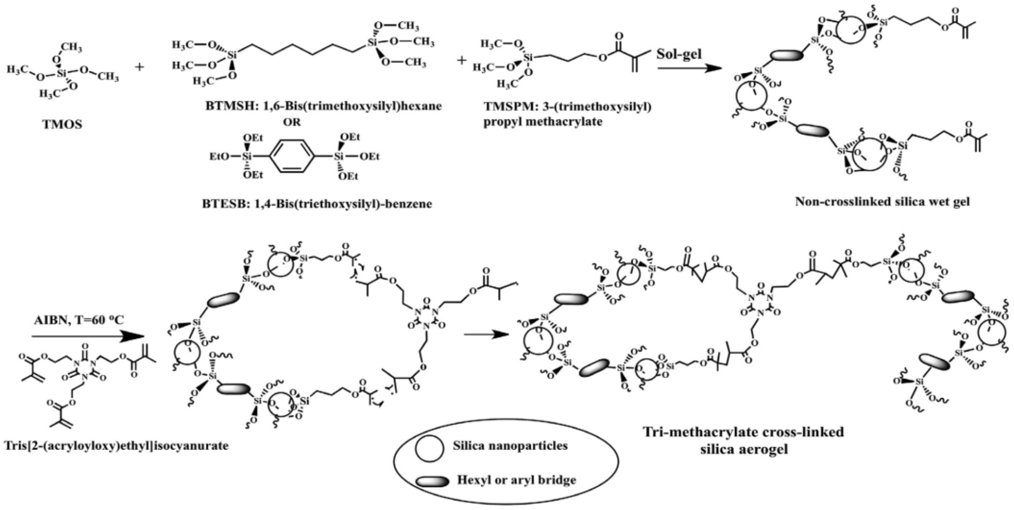
1.2. Aerogel formation

A gel is generally built up by a solid network structure surrounded by a liquid. Aerogels are materials where the liquid has been removed and replaced with a gas (often air).



There are many different types of aerogels with different chemical compounds building up the gel network. The compounds can be anything from metal oxides and silica oxides to inorganic-organic hybrids as well as organic compounds. These chemical compounds form particles and agglomerates that build up the gel network. In figure 2 these particles are illustrated as circles. The network structure is very complex and is similar to that of foam. Aerogels can either be made as intact bodies, monoliths, when dried from the wet gel or as smaller agglomerates suspended in a solution.

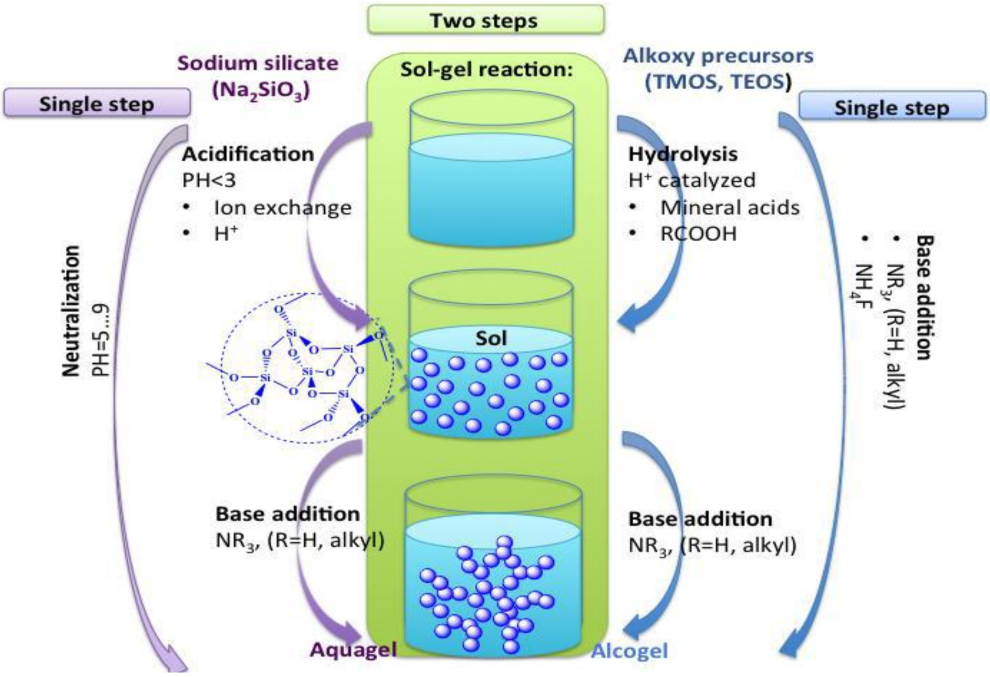
A model to describe aerogels is to picture them as cellular materials where the structure and shape of the network is approximated as cells. These cells have a certain geometry thatmrepeatedly builds up the structure. The aim of a model like this is to get a well-defined and uniform geometry of the network structure in order to better explain the mechanical behavior of the material. Ashby used the model of a hexagonal cell network in order to describe the
mechanical behaviour of a cellular structure under compression.



1.2.1. Silica (SiO_2) based aerogel

Silica based aerogel are widely used. They been invented by Kistler, in 1931 [1] when he attempted to replace the liquid inside of gels with gas. However, silica (SiO_2) gels by themselves are abundant in nature (opals and agates), their synthesis being firstly reported by Ebelmen in 1844. The SiO_2 gel usually has a formulation of $SiO_x(OR)_y$ or $SiO_x(OH)_y(OR)_z$, where R or OR groups are designated for alkyl or alkoxy groups; in the case of incomplete condensation y and z take an integer. Kistler prepared the first aerogels from sodium metasilicate (Na_2SiO_3) – water glass – by reacting this salt with an acid, such as HCl, in aqueous solution.

Sodium metasilicate salt is water-soluble, basic, relatively low-cost and widely abundant. The aquagel obtained from this precursor can be obtained directly from a single step sol-gel procedure by a simple neutralization or by a more elaborate two stage reaction of acidification/ ion exchange followed by the addition of a base. the whole procedure of aerogel formation from sodium silicate takes more than a week and, there is not much flexibility in the controlling of hydrolysis and condensation reaction rates at a preferred level to tailor microstructure and macroscopic properties of end material. Presently, this old technology of preparation of aerogels with water-glass retreats; by a two-stage sol-gel reaction, the difficulties mentioned above are to some extent mitigated.



1.2.2 Inorganic silica aerogel

Organic–inorganic hybrid materials are a new category of modern materials that lie at the interface of organic and inorganic compounds. Their synthesis offers an exceptional opportunity to combine the properties of both realms to develop entirely new tailor-made compositions with unique properties. The combination of organic and inorganic components can be carried out either by simple physical mixing of the relatively large particles in the micrometer scale or at nano/molecular scale ranges by creating a thoroughly dispersed and homogenized mixture from both components. According to the Sanchez *et al.*, most of the hybrid materials that come into the market have been synthesized and processed by soft chemistry developed in the 1980s.

There are several works that have been devoted to the modification of the silica aerogels with an organic component with the prospect of expanding their potential applications. Indeed, hybridization of silica aerogel with different organic components has been developed due to the several reasons. Firstly, the fragility, low mechanical strength of the network of silica aerogels imposes severe restrictions to their different potential applications, especially where the monolithicity and in turn the load bearing are the most important features for the particular application requirements. Secondly, the strong hydrophilic properties of pristine aerogels make them quite unstable in the atmospheric conditions and, therefore, impose a great obstacle for their efficiency and lifetime. Hybridization resolves the above-mentioned issues of silica aerogels by endowing the hydrophobicity to the system, which makes handling and processing easier and also provides mechanical strength.Additionally, in the case of aerogels, hybridization should preserve or have minimum effects on the outstanding properties of silica aerogels, such as high thermal insulation, transparency, low density and porosity of aerogels.

There have been several attempts on the preparation of silica aerogel composites by embedding organic monomers or polymers inside of gels and establishing physical bonds between the building blocks of both components. This is achieved by dissolving the organic part inside the silica precursors solution and, once the gel forms, the organic component is trapped inside it, leading to the formation of interpenetrated networks. However, in most cases the resulting hybrid material fails to meet the anticipated hybrid features due to the easy leaching of organic moieties or polymers from the wet gels during supercritical drying and associated washing steps.

1.2.3 Organic aerogel

Organic aerogels were firstly reported in the same period as inorganic aerogels. However, the systematic investigation on this aerogel was delayed for almost 60 years after Kistler's first report . Hereafter, in 1989, Pekala reported the bottomup approach to preparing phenolic resin-type aerogels through basic condensation of resorcinol with formaldehyde (RF), which are also being referred as ''resorcinolformaldehyde'' aerogels. Earlier investigations of organic aerogels were only limited to the further optimization and improvement of Pekala's RF aerogels and, for several years, this material was still referred as ''organic'' aerogels in the literature. But, after some time, other types of polymeric aerogels have been synthesized based on formaldehyde-type resins chemistry such as melamine-formaldehyde, cresolformaldehyde, phenol-furfural.

Under the alkaline condition, resorcinol reacts with formaldehyde to form mixtures of addition and condensation species in the low-viscosity sol. In the early stage of the sol-gel reaction, these species make RF clusters, which in turn undergo further reaction during gelation to prepare highly cross-linked interconnected colloidal-like networks.

Due to the facile change in the properties of organic aerogels by selecting appropriate polymeric systems and straightforward polymerization processes, and, also, due to their remarkable mechanical strength, these aerogels are currently being used for some applications that cannot be achievable by silica aerogels, for example in ballistic protection (armor).

II. LITERATURE REVIEW

Sr. No.	Paper Title	Name of Author	Findings
1	Synthesis of lightweight polymer-reinforced silica aerogels with improved mechanical and thermal insulation properties for space applications[3]	Hajar Maleki, Luisa Durães, António Portugal (2014)	- When compared to the other types of aerogel, the reinforced BTESB based aerogel, despite of higher extent of cross-linking , shows quite ordered and larger mesopores, leading to further improvement in terms of thermal insulation performance
2	Synthesis and characterization of novel phenolic resin/silicone hybrid aerogel composites with enhanced thermal, mechanical and ablative properties[1]	Rongying Yin, Haiming Cheng, Changqing Hong, Xinghong Zhang (2014)	- A single-step, one-pot, sol-gel polymerization process, together with solvent exchange and APD process, was developed to fabricate lightweight PR-Si hybrid aerogels -CBCF/PR-Si aerogel composite exhibiting high thermal stability, good mechanical properties, and low thermal conductivity the aerogel composites derived good thermal ablative and insulative properties
3	Lightweight superinsulating Resorcinol-Formaldehyde-APTES benzoxazine aerogel blankets for space applications[11]	Sandrine Berthon-Fabry, Claudia Hildenbrand, Pierre Ilbizian (2017)	- In this author concluded that thermal, chemical and hydric characteristics of the aerogels depends on the foemulation of sol. - Material density increases with an increase of %solid in solution.Thermal conductivity increased with density but depended on %solid for aerogel.
4	A Theoretical Model for the Effective Thermal Conductivity of Silica Aerogel Composites[9]	Yan-Jun Dai, Yu-Qing Tang, Wen-Zhen Fang, Hu Zhang, Wen-Quan Tao (2017)	- In this author concluded that the porosity of the aerogel matrix has a significant influence on the effective thermal conductivity of aerogels. -There exists an optimal porosity to minimize

			the effective thermal conductivity, and the optimal porosity increases with temperature. -The radiative thermal conductivity increases with temperature.
5	Multi-later insulation model for MASTER-2009 [5]	Sven K. Flegel , Johannes Gelhaus, Marek Mockel, Carsten Wiedemann, Holger Krag, Heiner Klinkrad , Peter Vorsmann (2016)	- The area-to-mass ratio of the debris information found in the literature for commonly used materials and configurations, reflectivity, deformation and tumbling motions. Size estimates for fragmentation induced MLI debris are established based on ground tests. For delami- nation debris, reasonable assumptions are applied in deriving size distributions. The rate of deterioration of MLI is important in establishing time functions for the rate of delamination
6	Effects of humidity on thermal performance of aerogel insulation blankets[8]	Atiyeh Hoseini, Majid Bahrami (2015)	- Author concluded here that moisture content increased at higher RH and lower temperature. -Thermal conductivity cyclic tests showed that it took approximately six cycles till the effective thermal conductivity reaches its maximum, which means the material was holding all the humidity that it could.
7	Facile fabrication of superhydrophobic, mechanically strong multifunctional silica-based aerogels at benign temperature[7]	Shuaiqiang Lia, Hongbo Renb,Jiayi Zhub, Yutie Bib, Yewei Xua, Lin Zang (2016)	- In this study, author found out that aerogel have excellent properties of being a lightweight,superhydrophobic, mechanically strong multifunctional silica-based aerogel, in which multiple functionsare realized in a single material, it is believed that the multifunctional aerogel could be potentially useful in the fields of defence, civil and building related applications.
8	Synthesis and Biomedical Applications of Aerogels: Possibilities and Challenges[4]	Hajar Maleki, Luisa Duraes, Carlos A. Garcıa-Gonzalez, Pasquale del Gaudio, Antonio Portugal, Morteza Mahmoudi (2017)	- The adjustable chemical composition and high porous network together with the high mechanical strength of some aerogel formulations have satisfied the tissue engineering application requirement that is not easily achievable by other porous biomaterials. The major attempt of this paper was to indicate that by tailoring chemical components, manufacturing, and processing, aerogel could become appropriate and versatile material for many biomedical applications.

III. MANUFACTURING AND EXPERIMENTAL CALCULATION

3.1 Manufacturing

1. Dilute concentrated ammonium hydroxide i.e to combine 4.6g concentrated ammonium hydroxide with 1000 ml of water in a glass or plastic bottle.

2. Mix the TMOS and methanol i.e. Combine 10.2 g or 10 ml tetramethyl orthosilicate (TMOS) with 7.82 g or 10 ml methanol in a glass beaker. Stir until mixed.

3. Mix the ammonium hydroxide solution with methanol. Combine 5 g or 5 ml of the stock solution previously prepared with 7.92 g or 10 ml of methanol in another glass beaker. Stir until well mixed.

4. Pour the catalyst solution into the alkoxide solution. Carefully pour the catalyst into the alkoxide and stir with a glass stirring rod until completely combined.

5. Transfer the sol into molds. Line your molds with silicone-based baking paper before pouring the liquid sol into them. Let the sol sit until gel forms. TMOS is the source of the silica in this method. The water allows the TMOS to polymerize, and the methanol lets both the water and TMOS enter into the same phase so that they can react. The ammonium hydroxide lets the reaction go faster.

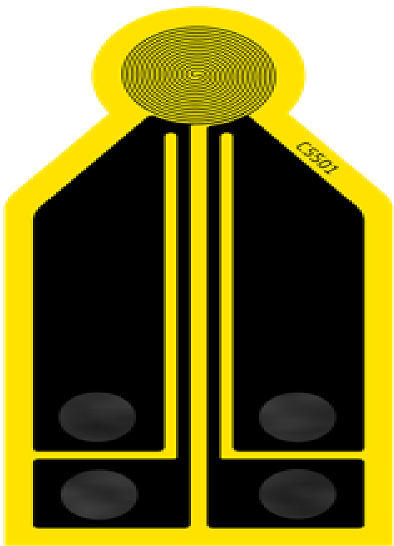
6. After the gel sets, place it under methanol and let it age for a full 24 hours, at minimum.

7. Diffuse the water out. Change the methanol out for fresh methanol, or acetone at least four times over the course of a week.

8. Dry the gel in your supercritical dryer. Place the gel in the supercritical dryer's compartment and heat the carbon dioxide through its critical point, 31.1 °C (88.0 °F) and 72.9 bars, at a pressure of about 100 bars. Super critical drying causes the methanol to get drawn out of the gel. Depressurize the machine at a rate of about 7 bar h-1. When done, you should be left with a finished silica aerogel.

3.2 Experimental measurement

In the present paper, the Hot Disk method based on the transient plane source method is adopted to measure the effective thermal conductivity of aerogel composites at different temperature. The Mica 4922 which can withstand the temperature up to 1050K is adopted. And the measurement time is set to be 160s, and the output power is 0.005W[10].



The effective thermal conductivities of aerogel within the temperature range from room temperature to 1000 K have been measured by our experimental system. For material, the porosity is 0.8591, the fiber volume fraction is 0.51%, the opacifier volume fraction is 1%, the opacifier is SiC with diameter 3.5μm and the fiber is SiO2 with diameter 6μm.

3.2.1 Results

Temperature(K)	300	400	500	600	700	800	900
effective thermal conductivity(W□(m□K))	0.031	0.034	0.036	0.038	0.041	0.044	0.055

IV. CONCLUSION

In the present paper, an engineering model for fast evaluations of the effective thermal conductivity for aerogel composites is developed. To get the accuracy of the proposed model, the Hot Disk thermal constant analyzer based on the transient plane source method is adopted to measure the effective thermal conductivity of some aerogel composites. The influences of the environmental parameters such as temperature on the effective thermal conductivity of aerogel composites are investigated. The contributions of the gas heat conduction, solid heat conduction and thermal radiation to the total effective thermal conductivities are decomposed to determine the dominant contribution factor of the effective thermal conductivities of the silica aerogel composites.

Following conclusions can be made:

1. The porosity of the aerogel matrix has a significant influence on the effective thermal conductivity of aerogels. There exists an optimal porosity to minimize the effective thermal conductivity, and the optimal porosity increases with temperature.

2. For the pure aerogels, the radiative thermal conductivities increase drastically when temperature increases and become the dominant contribution factor at high temperature; the effective thermal conductivities of aerogels vary with pressure as 'S' curve. At relatively high pressure, the contribution of gas conduction becomes the dominant part.

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