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Thermal Conductivity Performance of Silica Aerogel after Exposition on Different Heating under Ambient Pressure

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Abstract:

The varied thermal conductivity (insulation) of silica aerogel with heating for different pH has been investigated, it has been depended on ambient pressure drying method in the preparing silica aerogel samples, also six different pH of samples (1, 2, 3, 7, 8 and 9) were treated under five degree of heating with (50,100,150,200 and 250) ^{O}C. This technique is important to test the carry-outs hydrophobic silica to temperature without high-quality material changes in the basic characteristics. The hot-wire technique is used in this work to examine the thermal conductivity, Fourier Transform Infrared Spectroscopy (FTIR) depended to characterize the bonds and their artificial by heating. Results show that the samples affected by heating through decreasing the density leading to obtaining more insulation metal, moreover varied pH is an important role in thermal conductivity. The average thermal conductivity of all aerogel samples in this work is (0.01- 0.0061 mW m^{-10} C^{-1}) this means that it is still below thermal conductivity for air equals to (0.02257) mW m^{-10} C^{-1} . Meanwhile, we concluded that the insulation property of silica aerogel is affected by heat treatment and gives it more thermal insulation property.

Key words: Density, Effect of heating, FTIR spectra, Silica aerogel, Thermal insulation.

Introduction:

The ability of a material to the assignment the heat is usually called thermal conductivity (TC), it is the transferring of heat energy per unit of time and per unit of surface area, divided by the potential difference of temperature. For Air thermal conductivity is near of (0.02257) mW m^{-10} C^{-1} (1, 2). For powders TC is considerably lesser than of bulk complements by (10–100 times) (3). As well as, for a same type of martial, it does not have the same value continuously; as a result there is changing of some parameters. The main features influenced on TC are humidity, density, porosity as well as the temperature of the material. With increasing humidity and density, thermal conductivity besides increasing (4, 5). Furthermore the structure of materials plays an important rule in increasing or decreasing (TC); for high dense solid materials are motivated to have high value of thermal conductivity, while materials with large proportion of holes air bubble or gas (have a high porosity) yield the lowest value of thermal conductivity (6, 7). Materials have the relative densities below 75 % and the sizes of particle less than (100 nm), heat flow is administered by contact resistance of interparticle (8).

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Due to the influence of their surface area and size of nanoparticles on insulation property, it has regularly employed in the production materials which have a high insulation property (9,10). Nanoparticle powders made by silica have received wide consideration due to their high insulation property, inorganic fibres have been added during the preparation (11, 12). The reducing thermal conductivity of powders a discrepancy scanning calorimeter examination precision, as a consequence of the thermal grades that evolution within the sample (13). There are several choices to measure the value of thermal conductivity, each one of them is not suitable for all type of materials, depending on the medium temperature and nature of metals (black, liquid or powder) (14). It can be attained through evaluating the thermal resistance of a powder is filling the volume between the concentric cylinder and a hot wire (15, 16) . Otherwise, it is possible to evaluate the passing hot source method, which stratifies a fixed power of heat (17). Another way is by "a hot wire method" use of to measure thermal conductivity of samples, this method is a kind of passing wire source manner a viable for examining "TC" of powder tasters, since it is a suitable way to evaluate "TC for powders", foams, fluids and melted plastics, a heated wire is introduced inside the material, the heat movements outward from the wire into the sample and the temperature conversion in the wire is register. With providing density and capacity, the plot of the wire temperature versus the logarithm of time is used to calculate thermal conductivity (18, 19).

There are many studies and researches interested in obtaining insulator with the lowest thermal conductivity. Nishant Kumar and others checkup the thermal conductivity of Nanofluids is represented by SiO_2-Cu/EG and SiO_2-Cu/Water, which have density nearby SiO_2 but the isolation property is similar to Cu (20). Sundar et al. examined the influence of particle size, temperature, and volume fraction of silicon oxide nanoparticles on heat flowing of nanofluid, from the experimental results the comparison presented that the perversion of studied data was close together (21). Wei et al. calculated the thermal conductivity of tetrahydrofuran clathrate hydrate-nanoparticles with changing with temperature, with the presence and absence of sodium dodecyl sulfate. The results indicated that the increase of mass fractions of nanoparticles leads to increasing thermal conductivity (22). Masihollah Ahmadi Esfahani and Davood Toghraie used water ethylene glycol and silica as substructure of nanofluid then they measured thermal conductivity with different fraction of volume and heating ranged from 25 to 50°C, their results indicate the maximal heat flowing recorded in the portion of the volume of 5% at temperature 50 °C (23). Silica aerogels still have lower thermal conductivity than air, it is highly insulating materials and that is because of nanometer pore size and porosity. Kistler established that the heat flowing of an aerogel is be about 0.025 W/m. K at normal pressure in air and in the order of (0.015 W/m. K) at super conditions (24). Aerogels together with evacuating insulation panels are one of the new promising high performance thermal and acoustic insulation materials (25).

In this work, thermal conductivity was evaluated by using "a hot wire method" for hydrophobic silica aerogel with different pH and the effect of heat treatment on their thermal insulation and the relation between reduced thermal conductivity with pH and density were studied.

Materials and Methods:

Hydrophobic silica aerogel was prepared based on the multiple chemical modification, included mixed tetraethoxysilane (TEOS) (1M as precursors) with ethanol (catalysis) and (H_2O+0.5M HCL) in the first step, the mixture hydrolyzed for 24 hrs., in the second step (NH_4OH+NH_4F) is used as base catalysis added to hydrolyzed mixture the addition with different amount in order to obtain on different pH of samples 1, 2, 3, 7, 8 and 9, the alcogel aged for 3hrs. in ambient pressure (atmospheric pressure) and then washed in pure ethanol four times every 24hrs. The modification of alcogel was by mixed trimethylchlorosilane (TMCS) with n-hexane and socked the samples in the above mixture at 60°C for 24hr then replaced the liquid with another and repeat this process four times every day, the last step the modified gel was washed with pure n-hexane and let it dry at room temperature, five values of heating for samples were treated as following (50,100.150, 200 and 250°C) respectively. Density of each sample for every heating was measured using a known volume of the aerogel and its mass, Hydrophobicity of samples was tested by computing the contact angle of water droplet on top of surface of sample "the height (h) of drop and contact width (w) of the droplet" were calculated by using "image-processing software", The contact angle was then evaluated by equation one (26):

$$\text{Contact angle } (\theta) = 2tan^{-1}\left[\frac{2h}{w}\right] \quad \ldots\ldots\ldots \quad 1$$

two to four different images of drops of water were put on the top surface of the sample, the average value of contact angle calculated as an above equation, "A Hot wire method Analyzer" was used to calculated quantity thermal conductivity of aerogel powders. Heated wire was bounded inside the powder to be investigated, the surface of the wire was stationary at a distance (r) from "thermocouple". With a constant electric heating power, after a heating time (t) the rate at which the heat rised at point (r) with obtaining over time the changing of temperature, the "TC" of the "powder" could be easily calculated in equation two (27):

$$k = \frac{q}{4\pi}\frac{lnt_2 - lnt_2}{T_2 - T_1} \quad \ldots\ldots\ldots \quad 2$$

(k) is the "thermal conductivity of the powder", (q) is a power of the electric heating for unit length, T_2 and T_1 are the temperatures with the time(t_2) and (t_1) respectively. Fourier transform infrared spectroscopy (FTIR-8400S Fourier Infrared spectrophotometer SHIMADZU) spectra were used to detect the chemical bonding of the silica aerogel, these provided the indication about numerous chemical bonds accountable for heating samples, such as "Si–O–Si, C-H, Si–C and O–H".

Results and Discussion:

Figure 1 shows the FTIR spectra of silica aerogel for different temperatures (50, 100, 150, 200 and 250°C), there are many obvious effects in the FTIR analysis, including the effect of surface improvement on the sample and the effect of heat on the increase of some of the properties of CH, Cl, and the reduction of the water or OH forming of the water molecule. On the other hand, the peaks which lie at 1683 cm^{-1} and the broadband at region 3575 cm^{-1} are attributable to (-OH) groups (28). For comparison between the lowest and highest temperature, the effect of heat treatment is very clear from decreasing of peaks at 3575 and 1683 cm^{-1} because of the evaporation as a result of heat and interaction alcogel with TMCS which is reduced OH and replace it with CH and/or Cl band.

The broadband at 1050 cm^{-1} represents to Si-O-Si this is silicon oxide from TEOS this bond does not influence by this heating, because the silicon in nature bears the high temperatures up to 1500°C, so it can say the region of silicon oxide could not be influenced in these temperatures (28). The band at 900 cm^{-1} refers to Si-OH at 50°C is clear as a weak peak then it began to disappear as the heat rise; because of evaporation. It can be saied that we can depend on FTIR analysis as one of the ways to study the effect of heating on silica aerogel (29,30). For the same temperature with different pH, the FTIR spectra are does not given deferent results, so it can said that the varied pH it has no role that affects thermal conductivity.

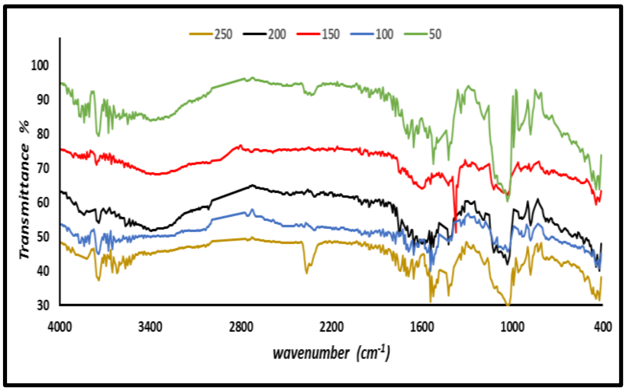

Figure 1. FTIR spectrum of silica aerogel with different temperature.

Table 1 shows the effect of heating on density for all different pH samples, Table 2 shows the effect of varied heating on thermal conductivity.

Table 1. Display the density for aerogel with different pH and temperatures.

T(°C)	*Density g/cm³*					
	pH1	*pH2*	*pH3*	*pH7*	*pH8*	*pH9*
50	0.301	0.421	0.378	0.184	0.22	0.281
100	0.287	0.39	0.322	0.126	0.172	0.224
150	0.251	0.388	0.3	1.09	0.131	0.2
200	0.238	0.361	0.272	0.0549	0.111	0.174
250	0.2	0.328	0.22	0.0381	0.104	0.12

Table 2. Display the thermal conductivity for aerogel with different pH and temperatures.

	The degree of heating of the samples for one hour				
	50°C	100°C	150°C	200°C	250°C
pH	Thermal conductivity (mW $m^{-10}C^{-1}$)				
1	0.090	0.078	0.071	0.059	0.042
2	0.088	0.081	0.079	0.077	0.073
3	0.086	0.081	0.073	0.066	0.060
7	0.0107	0.0099	0.0091	0.0089	0.0086
8	0.0093	0.0085	0.0077	0.0069	0.0061
9	0.0120	0.0118	0.0108	0.01	0.0098

Figure 2 illustrates the relationship between the increase of temperature and decreasing of density. The increasing of temperature leads to decreasing of density for all different pH of silica aerogel samples since the increase in solid components will decrease the thermal conductivity; therefore, low porosity, as well as low-density materials, always are qualified as low thermal conductivity materials. Moreover the varied pH, has an important role on thermal conductivity. Figure 3 demonstrates the behaviour matching between thermal conductivity of silica aerogel with different pH.

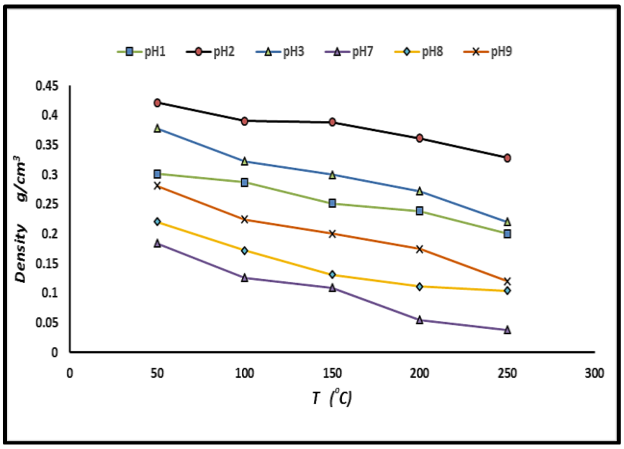

Figure 2. The density of silica aerogel with the different temperature at different pH.

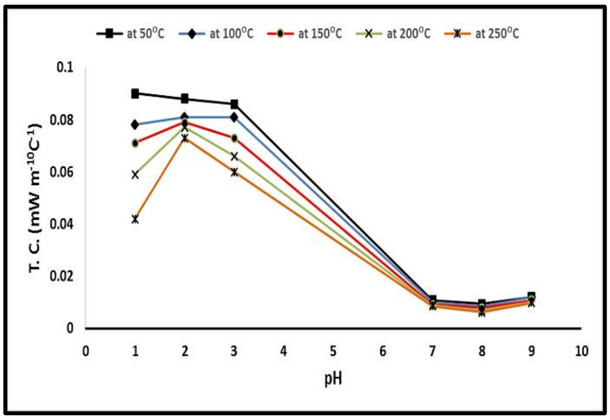

Figure 3. Thermal conductivity of silica aerogel with the different temperature at different pH.

In general, the silica aerogel possesses so small (0.9-10.1%) portion of solid silica (29). Where silica aerogel has three-dimensional networks that make solids consist of actual small particles connected in the aerogel network in three dimensional with many ends known as dead ends. Therefore, the transparency of thermal through the solid fraction of silica aerogel occurs through the snaky pathway and it is not chiefly effective leading to low thermal conductivity in such type of materials. In addition, the porous of the sample is not closed (this is nature structure of silica aerogel) (30) that will cause the gas passes through and that is another reason for lowering the conductivity.

Conclusions:

Since the aerogels are commonly thermal insulator material, the present study confirms this concept as well as, there is a significant effect of the starting pH value on the aerogels thermal conductivity. While the aerogel density is strongly depending on temperature values. The average thermal conductivity of all aerogel samples are (0.01- 0.0061 mW m-10C^{-1}) this means that below from thermal conductivity of air. The insulation property of silica aerogel affection by heat treatment and give it more insulation property.

Conflicts of Interest: None.

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أداء التوصيل الحراري لهلام السيليكا بعد التعرض لدرجات تسخين المختلفة تحت الضغط الجوي الاعتيادي

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الخلاصة:

لقد تم التحقق من التغير الحاصل في التوصيلية الحرارية (قابلية العزل الحراري) لهلام السيلكا لعينات تختلف في دالة الحامضية ،تم اعماد الضغط الجوي الاعتيادي في اثناء تحضير عينات هلام السيليكا. كما اجريت الدراسة على ست قيم للدالة الحامضية للنماذج وهي (1 ، 2 ، 3 ، 7 ، 8 ، 9) عند التسخين بخمس درجات حرارة مقدارها (50،100،150،200،250) درجة سيليزية، هذه التقنية مهمة في اختبار مدى تحمل مادة السيليكا الرافضة للماء للحرارة العاليه دون تغير صفاتها الاساسية. تم في هذا العمل استخدام تقنية الأسلاك الساخنة لفحص الموصلية الحرارية. اعتُمد التحليل الطيفي بالأشعة تحت الحمراء من فوريير (FTIR) في التمييز بين الروابط وتأثرها بالتسخين. اظهرت النتائج أن العينات تأثرت بالتسخين من خلال النقصان في الكثافة مما ادى للحصول على مزيد من المعادن العازلة ، بالإضافة إلى ان دالة الحامضية المتنوعة لها دور مهم على الموصلية الحرارية. في هذا العمل معدل الموصلية الحرارية لجميع عينات الهلام كان (0.01- 0.0061 mW $m^{-10}C^{-1}$) مما يعني انه اقل من الموصلية الحرارية للهواء الذي يساوي (0.02257) mW $m^{-10}C^{-1}$. من ذلك استنتجنا ان خاصية العزل الحراري لهلام السيليكا تتاثر عند معاملتها بالحرارة وتعطيها صفة العزل الحراي العالية.

الكلمات المفتاحية: كثافة، تأثير الحرارة، طيف FTIR ، هلام السيليكا، العزل الحراري.