# Insulation for a Thermos Through the Use of Recycled Materials and Nanofoam

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**Abstract:**

The goal of this project was to take advantage of the capabilities of nanotechnology by using the room temperature sol-gel process to form a silica nanofoam composite with a common household foam, in an effort to synthesize a cheap, lightweight insulator for use in a thermos. Through testing of hybrid insulators, it was determined that a silica nanofoam and packing peanut composite combines the natural insulating properties of the packing peanuts and of the silica nanofoam to make an insulator for a thermos.

**Introduction – Nanofoams and Gels**:

With rising temperatures and record levels of pollution, global warming is becoming an even more pressing problem. Because of this, concern for the well-being of the environment has grown to levels that have never been seen before. This new trend in environmental concern has developed into hundreds of "green" solutions and energy-saving schemes requiring recycled materials and interesting new ideas. Examples of these "green" innovations are UltraTouch, an alternative insulation made of recycled denim, and a modified cellulose foam [3]. Simultaneously, the alarming rate of size-reduction in technology has spurred a flood of high-performance materials and innovative processes of material synthesis. Coined by Norio Taniguchi, "nanotechnology" provided an extremely promising solution to the problems of scaling down machine sizes [2]. Materials that have a dimension measuring less than 100 nm, or one ten-millionth of a meter in length or are made one atom or molecule at a time qualify as nanotechnology. In this project sol-gel a nano-material synthesis method was used to synthesize a cheap, efficient insulator of nanofoam while utilizing the most common "green" solution: recycling.

**Background Information – The Sol-Gel Process:**

Due to the pockets of air in foams, foams have a low density compared to other materials. They are extremely useful as commercial materials due to their light weight. The pockets of air within foams give them numerous characteristics that allow them to act as efficient sound and heat insulators. Nanofoams are very similar to normal foams in that they have small pockets of air, but they have other qualities that regular foams usually do not have, such as transparency. Nanofoams, unlike other nanomaterials, have nano-dimensions that do not pertain to the foam itself but to the pockets of air that are dispersed throughout it. The unique quality of nanofoams, the size of their holes, and their varied means of synthesis make them interesting materials with several manifestations capable of many different applications. One method used to synthesize a nanofoam is the sol-gel process. This process uses the chemical processes of hydrolysis and polymerization, which both occur at room temperature and can make macromolecules without the use of high temperatures. This is important because it means that the sol-gel process can be done at minimal expense under ordinary room temperature conditions.

Nanofoams that are made through this process are very porous, and their pores are less than 100 nm in diameter. Because the pores are smaller than the wavelength of visible light, they are invisible to the human eye, making them indistinguishable from their non-foam counterparts. The amorphous quality of foam created through the sol-gel process allows the foam to be easily shaped into a mold; it can form around other objects, making it a useful and flexible adhesive. Research has already been conducted to discover new ways to produce and shape nanofoams, such as spinning, dipping, spraying, ink-jet printing or roll coating [4]. Sol-gel film has been used as a durable adhesive in metal coating and as a preventative measure against rust due to the film's ability to bond to metal [1]. Not only are sol-gels versatile on their own, but they can also take on the properties of other materials. Through the technique of "doping," other materials are introduced into the nanofoam during creation, and the foam takes on the qualities of that composite material, making it possible to create a variety of different foams. These foams can be molded into dielectric foams, thin membranes or even conductors for a variety of different applications.

Our project involves preparing a silica (SiO2) by nanofoam using the sol-gel process. Silica, most commonly found in sand, is usually melted at high temperatures to form glass. In the sol-gel process, silica is prepared as a solution of monomers of silicon ions attached to four alcohol groups. Through hydrolyzation and polymerization, the silicon compounds are formed once again into SiO2 this time in the form of a gel. When left out to air-dry, the water in the gel evaporates, and its surface tension causes the silica nanofoam to shrink. Once all of the water is gone, the final product is once again SiO2, but this time it is in the form of glass. When glass is created with the sol-gel process, however, it has the additional property of being a nanofoam. The solid nanofoam appears to look the same as normal SiO2, but it is really filled with nano-sized holes.

**Experimental Design:**

To experiment with the sol-gel process, five different silica sol-gel samples were created. Silica gel was chosen because it is the cheapest of the gels and an effective insulator. These samples had different materials acting as catalysts to speed-up the gelling process. Isopropyl alcohol, table salt, nitric acid, acetic acid, and cobalt were used. One of the samples of silica sol-gel was composed of nitric acid and cobalt, which gelled into a soft, uniform, pink gel that was slippery and moist to the touch. This gel hardened incredibly slowly, and as each day passed, it gained more cracks due to its shrinking and its adhesion to the petri dish. Another sample used only cobalt. This sample gelled rather quickly and cracked into many smaller, iridescent pieces of glass that resembled amethyst. The most active of the additives to the silica was table salt (NaCl). Within minutes of adding the salt to each of these mixtures, the colloid began to gel.

From these samples, it was evident that table salt was the most effective gelling agent. It greatly accelerated the sol-gel process. Cobalt was relatively ineffective; the sample that contained only cobalt did not harden until several days later. Nitric acid was also not nearly as potent a gelling agent as table salt: the smooth, pink sample, when observed thirteen days later, was still not completely gelled. Using this information, it can be concluded that table salt was the quickest gelling agent. Table salt was the best gelling agent because it ionizes well in water. When silica molecules disperse in water, they have a slightly negative surface charge, which causes them to repel each other. When salt is also disassociated into the water, the silica molecules form around the positively charged sodium ions, and as the water evaporates, the silica molecules move closer together so that they eventually form a solid nanofoam.

To test the insulation capabilities of common foams, eleven different foams were collected: packing peanuts, polyurethane sponge, bubble wrap, dish sponge, vermiculite, cotton balls, shaving cream, ceramic balls, marshmallows, and two types of polystyrene foam. These foams were chosen because they are readily available, cheap, and they represented a wide variety of different types of foam.

First, an ice water bath was prepared. Then, a sample of foam was used to cover the bulb of the thermometer. After recording the temperature of the room, the thermometer was placed in the ice water bath, and the timer was started. The lengths of time that it took for the temperature reading to drop by one degree, five degrees, and ten degrees Celsius were noted. All of the foams were tested by repeating this process.

Next, a hot water bath was prepared. Aside from observing one degree, five degree, and ten degree increases in temperature, the same essential procedure was implemented in testing the insulation capabilities of all eleven types of foam using a hot water bath.

Finally, seven different possible samples of composite materials that could effectively insulate a thermos were created. First, colloidal silica and table salt were poured into a small jar, and this solution was carefully stirred. Then, four plastic test tubes were stuffed with packing peanuts and filled with the colloidal silica and salt solution. Two of these four test tubes were capped and put aside to dry. The other two were left open to air dry. Following this, another test tube was filled with shaving cream and the colloidal silica and salt solution and left open to air dry. A sixth test tube was stuffed with cotton balls and filled with the colloidal silica and salt solution and also left open to air dry. Lastly, broken pieces of packing peanuts were placed in a petri dish, which was then filled with the colloidal silica and salt solution. This sample was closed and put aside to dry.

**The Results**

The results of the heat insulation experiments indicated that polystyrene packing peanuts, cotton balls, and shaving cream were the three foams that took the longest overall times to conduct heat and, therefore, were the best insulators. The data indicated that dish sponge, polyurethane sponge, and bubble wrap were the least effective heat insulators.

When the samples of composite foam insulators were examined, all of the samples that included packing peanuts had hardened exactly as expected, forming a hard glaze around the packing peanuts and holding them together. The cotton balls in the cotton-ball-silica composite were hard to the touch, and they, too, had adhered to each other very well. Both the packing peanuts and the cotton balls formed into a usable composite material. However, the results of the shaving cream sample were not as ideal because the shaving cream and silica separated while drying. These experiments were useful in determining the composition of our final product.

The experiment with heat insulating properties of foams yielded the following results:

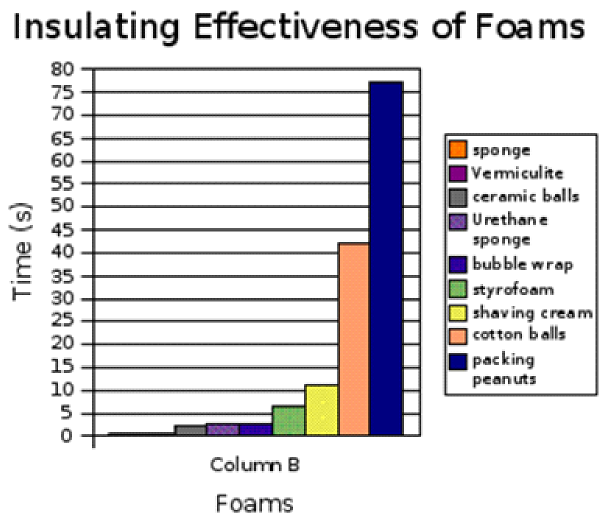


**Figure 1. Average time required to change the temperature of a foam by one degree Celsius for each tested foam**

## Discussion:

The first experiment dealt with which materials could be added to colloidal silica in order to form a better gel in the least amount of time. All of the solutions that included nitric acid took more than a week to fully harden. The mixture that included nitric acid and cobalt turned a uniform, translucent pink color after the first day of gelling, but even after a week, it remained soft to the touch. In the mixture with only cobalt, the cobalt clumped together into large, purple chunks, and the mixture hardened and cracked very quickly. By the first examination, the other solutions, which contained silica and salt, had already gelled, and a few days later, had hardened completely into very small pieces of opaque glass. The colors of each of these samples differed, depending on the amount of cobalt present, but all of them were opaque, hard and fractured. Due to the time intensive nature of this project, a quick-gelling mixture of silica was very important, so salt was chosen to be used for all subsequent silica mixtures.

There were three obvious tiers of insulating effectiveness. The least effective insulators were sponge and vermiculite. Both the sponge and the vermiculite insulated thermometer increased in temperature by over ten degrees in less than five seconds when added to the hot water. The foams that could be placed in the middle tier in terms of their effectiveness in insulating the thermometer were the small ceramic spheres, the polyurethane sponge and the bubble wrap. For these three foams, the thermometer took about twenty-five seconds to increase in temperature by ten degrees Celsius. Finally, the foams that would be classified in the highest tier were packing peanuts, cotton balls, and shaving cream. These three foams each took over a minute to rise in temperature by ten degrees Celsius. Not only this, but when surrounding a thermometer placed in cold water, the cotton-ball-wrapped thermometer took three minutes and thirty seconds to drop by five degrees, and the thermometer wrapped in packing peanuts had even more pronounced insulating properties, as it took four minutes and fifty seconds for it to cool by only two degrees Celsius. In cold water, the shaving-cream-insulated thermometer performed well, but not nearly as well as the cotton balls or the packing peanuts had performed. The thermometer insulated with shaving cream lost ten degrees Celsius in one minute and fifty-one seconds.

Based on the observations of the sponge, vermiculite, packing peanuts and cotton balls, smaller pore size correlates with better insulating properties.

The aim of the final experiment was to find out which of the foams would be the most useful in the final product. The samples were made of cotton ball and silica composite, packing peanut and silica composite, and shaving cream and silica composite so that they could be examined and inspected for any flaws. After drying, the shaving cream and silica composite had separated into powdery, dry shaving cream on top and pure silica nanofoam underneath. Both the packing peanut and the cotton ball silica composites formed into their own solid objects held together by the silica nanofoam. The cotton balls and packing peanuts both worked well as a composite material with the silica nanofoam. From this information, only two choices remained for the composition of the final product. Either the final product would be made with cotton balls or packing peanuts. After some deliberation, it was decided that packing peanuts were the best choice for the composite material. They exhibited excellent properties as insulators; they easily joined with the silica gel into a composite material, and they are cheap, available, and often recycled. It was concluded that the best insulating material for the thermos would be the packing-peanut-and-silica nanofoam composite, which would be gelled using salt.

The final result of the project was a light-weight, cheap, easy-to-produce insulator that can be molded into any shape.

**Future Work – There's Still More To Be Done:**

Besides building a thermos using the composite foam product, an additional step can be taken to research further the insulating properties of various other nanofoams including aerogel, which was a foam of interest at the start of this project. Due to time constraints, making aerogel was not feasible in this project, but given more time and additional resources, experimentation with aerogel, which is a lightweight insulator, and other nanofoams could result in better insulation.

Several aspects of the final product could be improved in the future. Since there was not enough time for the seven composite foam samples to adequately dry, it is important, in the future, to test the relative insulation capabilities of the seven foams using the process outlined in this project and compare their insulation capabilities to that of pure colloidal silica. From these comparisons, it would be possible to determine how much the addition of a common foam to colloidal silica improves overall insulation.

It is also a possibility to gel multiple common foams into one nanofoam composite. Packing peanuts, cotton balls, and shaving cream were gelled separately, but a combination of all three or two of the three may provide better insulation.

Increasing the concentration of colloidal silica could also provide better insulation, and thus, it is important to experiment with different concentrations of colloidal silica to make a more effective insulator in the future.

Further investigation could be done to assess the utility of our foam in other applications including building insulation. Our material can potentially be used in walls, floors, and ceilings. It is lightweight and inexpensive, which allows for a variety of usages. In addition, the sol-gel process is such that the composite foam can be easily molded into any given shape. This allows for the foam to serve as a lightweight, inexpensive container for almost anything that requires insulation. Organ-carrying apparatuses, for example, rely on strong insulation to preserve the organ, and thereby ensure that a patient is not given a defective organ. Our insulation can also be used in refrigerated semi-truck trailers, which need to insulate large supplies of fresh food.

Within the broad scope of nanofoams, creating composite foam that can both insulate and provide soundproofing is a useful endeavor since such a foam is useful in a variety of ways.

A soundproofing and insulating foam would be valuable in the walls, floors, and ceilings of apartment buildings where families living in tightly-packed units would appreciate more privacy. There is still a lot of research to be done in the field of using nanofoam composite materials as insulators and beyond. Some day, perhaps, nanofoams will be as ubiquitous as common materials such as plastic.

**Conclusion:**

While foams may seem simple at a first examination, the depth of knowledge required to understand their properties and uses is vast. Nanofoams can be used for a variety of purposes, and as we found out, they work well as both insulators and as adhesives. When we began our project, we sought to garner a deeper understanding of foams, especially nanofoams, by making an insulator that would use recycled materials and would be suitable for use in a thermos. But when we completed our project, we had gained so much more. We accomplished our goals, and created a sample of our insulation using silica nanofoam and packing peanuts, and we also acquired valuable insight into the way that a material science laboratory works.

**Acknowledgments:**

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