Application of the Properties of Nano-Silica Gel Coatings: Modification of the Styrofoam Cup

Cliff Chao
cchao@ctemc.org

Ananya Joshi
ajoshi@ctemc.org

Emma McKee
mckeee14@aol.com

Emily Weng
emilyweng97@gmail.com

Samuel Yoon
samsyoon97@gmail.com

ABSTRACT

The temperatures of standard glassware and ceramics are nearly impossible to tell just by sight. Therefore, burns from touching heated surfaces are common in the laboratory and in the kitchen. The sol-gel process is a safe method to create foam under ambient conditions. Adding different chemical compounds causes the foam to have varying physical and chemical characteristics. This project focuses on studying the properties of catalyzed nano-silica foams and the application of these foams to kitchenware. A Styrofoam cup was coated with insulating foam consisting of colloidal silica solution, nitric acid, titanium dioxide, and polyethylene glycol. To make the cup heat-indicative, leuco dyes were placed under the coating. Finally, the rim of the cup was coated with an absorbent mixture of colloidal silica solution, titanium dioxide, and polyethylene glycol. The rim of the cup was able to absorb dyed liquids, and the foam coat on the cup functioned as an insulator. Although the foam coatings did not stay intact, the two coatings have properties that make them viable materials outside of kitchenware in the areas of nanofiltration and structural design.

1. INTRODUCTION

In 1994, seventy-nine-year-old Stella Liebeck suffered severe third-degree burns while drinking hot coffee at the McDonald's restaurant. Her case, which made headlines after she sued the corporation in a product liability lawsuit, was based on the fact that there were no warnings on the cup indicating that the coffee was too hot to touch. Ms. Liebeck won the case, but was physically incapacitated and continued medical treatment for two years after the incident.[1]

A heat-sensitive cup would have warned Ms. Liebeck that the contents of the cup and the cup itself were too hot to drink or touch. Ms. Liebeck is one of many who receive burns from kitchenware; for those seven and older, most burn injuries occur in the kitchen.[2] Cautionary measures can avert several of the injuries associated with scalding kitchenware.

Coffee cups now come with warnings that the cup may be too hot to touch, but there are few feasible ways to visually detect temperature changes. Thus, the development and application of heat-sensitive coatings to kitchenware would alert the user if the product is too hot to touch. This project tests thermal-sensitive and absorbent foam coat-

ings on Styrofoam cups. These foams will be created using the sol-gel process of creating nano-silica foams because they can be created under ambient conditions. Burns still remain a concern in the kitchen and the laboratory, so the application of foams created by the sol-gel process to Styrofoam can provide a realistic way to detect the temperature of a surface and the liquid inside.

2. BACKGROUND

2.1 NANOTECHNOLOGY OF FOAM

Nanotechnology is the practical application of particles between one and one hundred nanometers in at least one dimension.[3] These nanoparticles have increased surface area, which leads to altered chemical and physical properties, Common industrial foams are colloids with a dispersed phase of gas and a continuous phase of solid colloid. However, foams made using the sol-gel process start out as colloids with a dispersed phase of solid nanoparticles and a continuous phase of liquid solution. Scientists are interested in foams formed by the sol-gel process because the foams can be stronger or more chemically reactive. Scientists can manipulate sol-gel foams and their properties at the nanoscale to make foams suited for specific applications.[4]

2.2 THE SOL-GEL PROCESS

The sol-gel process is used to make foams in an ambient environment. The process converts individual nanoparticles in an aqueous or alcohol solution, or sol, to an inorganic network, which is a gel. The resulting product dries into foam. The base network is formed from the colloidal solution itself.

Adding precursors to the sol affects the chemical and physical properties of the base network.[5] Colloidal silica solution, titanium dioxide, and thermochromics are examples of precursors. Thermochromic dyes change color in response to temperature. Leuco dyes are a group of common thermochromic dyes.[6] Cold Activated Thermochromic Ink is used to respond to cooler temperatures (near or below 15ºC). High Temperature Thermochromic Ink is a leuco dye that changes color once the ambient temperature reaches levels that would be painful to touch (around 47ºC). [7] This project used the High Temperature Thermochromic Ink to indicate the pain threshold.

The chemical reactions behind the sol-gel process are a partial hydrolysis and a subsequent condensation reaction (Figure 2). The precursors in the solution are partially hydrolyzed and are then subsequently linked by a condensation reaction to the molecules of the solution. This results in a polymer chain which brings structure to the gel.

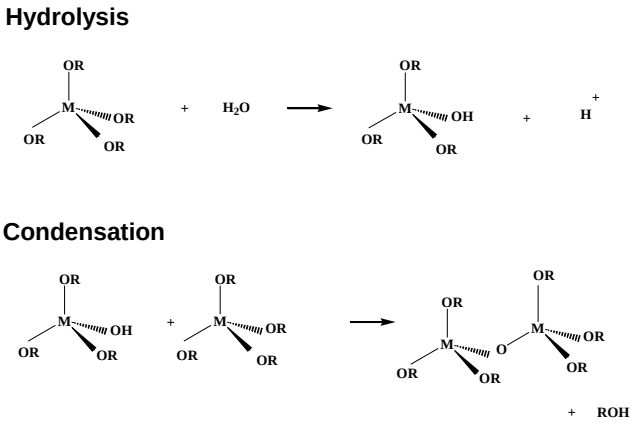

Figure 1: Hydrolysis and condensation diagrams[5]

Chemical catalysts speed up the formation of the foams. The two categories of catalysts are acids and bases. When the reactions are catalyzed by an acid, the molecules form long polymer chains. When the reactions are catalyzed by a base, the molecules form large clumps and are spaced out.[5]

The catalyst used determines several chemical and physical properties, such as po-

larity and porosity, on a molecular level. Porous materials have lower thermal conductivity and are consequently better insulators.[8] Absorption is also directly proportional to porosity. [9] To make a hydrophilic material, or a material that absorbs water, the material must be polar since water is polar.[10] Catalysts are important because without catalysts, it takes several months for the sol to harden into gel; with catalysts, the process rapidly speeds up.

3. METHODOLOGY

There are two distinct parts to the methodology – surveying the foams and developing the foam coatings for the Styrofoam cup. There were multiple rounds of testing to identify the best foams to use as the coatings and several methods for the coating process.

3.1. MATERIALS

3 Styrofoam cups	Plastic wrap
LUDOX colloidal silica solution (sol)	Cobalt chloride ($CoCl_2$)
Sodium chloride (NaCl)	Calcium chloride ($CaCl_2$)
Nitric acid (HNO_3)	Ammonium hydroxide (NH_4OH)
Titanium dioxide (TiO_2)	Polyethylene glycol (PEG)
Fluorescein	Food coloring (Red, Yellow, Green, Blue)
Paraffin wax	Clear nail polish
Neutral pH Glue	Water
Disposable pipettes	Scoopulas
Mood rings	Beakers
Petri dishes (large)	Petri dishes (small)

3.2. SURVEYING THE FOAMS

3.2.1. Creating Sol-Gels and Observing the Effects of Different Catalysts on Composition

Several tests helped determine which foams had the properties necessary to create functional coatings for the Styrofoam cup. Ten different combinations of the sol and the catalysts HNO_3, NH_4OH, NaCl, $CaCl_2$, and $CoCl_2$ were added to ten Petri dishes. The catalysts were added drop by drop until the mixture thickened or clumped together. These newly made gels were allowed to dry undisturbed in the laboratory over the weekend.

Figure 2: The ten Petri dishes after 50 hours of drying. From left to right: top row – (1) NaCl (low concentration), (2) $CoCl_2$ + NaCl + NH4OH, (3) HNO3, (4) NH4OH (low concentration), (5) $CoCl_2$ + NaCl + $CaCl_2$; bottom row – (6) NH4OH (high concentration), (7) $CoCl_2$ + NaCl, (8) $CaCl_2$ (low concentration), (9) NaCl (high concentration), (10) $CaCl_2$ (high concentration)

Density, absorbency, heat capacity, and filtration ability were tested in the laboratory through a series of small experiments.

3.2.1.1. Density and Porosity Procedure

A small piece (less than 1 cm^3) of dried gel was broken off and massed on an analyti-

cal balance. The x-, y-, and z-dimensions of the gel were then measured, and the volume was calculated. The measured mass was divided by the volume of the gel to obtain the density. This was repeated for each of the gels made, and the densities were compared to the experimentally tested densities of common industrial foams, including packing foam, Styrofoam, and shaving cream. The porosity of the gels was obtained by dividing the measured density of the gel by its theoretical density.

3.2.1.2. Absorbency Procedure

Two samples of a chosen gel were massed on an analytical balance. One sample was placed in a Petri dish, and 5 mL of ethanol was poured over the sample. If the sample was less dense than the ethanol, then the sample was held down with forceps. The second sample of the chosen gel was placed in a Petri dish containing 5 mL of water. The samples were then observed for any bubbling, cloudiness, or breakage over ten minutes. The samples were removed with tweezers, and the excess liquid was shaken off. The samples were massed, and the change in weight of the samples was recorded. This was then repeated for each gel. For comparison, the absorbency of aerogel, a gel that is 95% air, was also measured.

Figure 3: Samples of NH_4OH-catalyzed foam and NaCl-catalyzed foam in water and ethanol

3.2.1.3. Heat Capacity Procedure

Pieces of gel were placed in a small plastic bag. To test the extent of the thermal insulating property of the gels, a thermometer was placed in the middle of the bag so that it was surrounded by the pieces of the gels. A 250-mL beaker of hot water was heated up to 75°C. The bag was then secured in place with a rubber band and placed in the beaker of hot water. The bag and thermometer were slowly heated up over a period of 5 minutes, and the temperature was taken every minute.

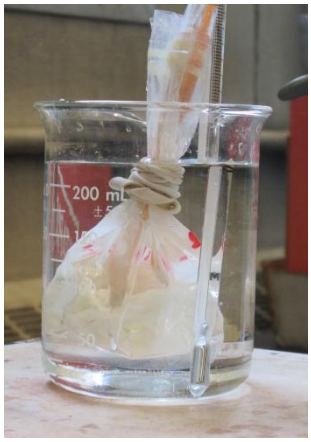

Figure 4: The set-up for taking the readings from the Heat Capacity Procedure

3.2.1.4. Filtration Procedure

100 mL of water were measured out using a graduated cylinder. Two drops each of red, yellow, green, and blue food dyes were added to the water. The graduated cylinder was covered with Parafilm and shaken until the dyes were dispersed throughout the water. A coffee filter was placed in a porcelain strainer funnel that rested on a ring stand. Underneath the strainer was a 100-mL graduated cylinder. A sample of the designated gel was then placed on top of the coffee filter, and 10 mL of the dyed water were poured into the funnel. The properties of the gel and the solution were observed and recorded after a day of drying.

Figure 5: Filtration procedure set-up

3.2.1.5. Scanning Electron Microscope

Samples of NH_4OH- and HNO_3-catalyzed gels were observed under a scanning electron microscope. The samples had been placed in a desiccator and coated in a thin layer of gold. Structural and compositional images and measurements were taken.

Figure 6: The samples of NH_4OH and HNO_3 that were plated in gold

3.2.2. Altering Concentration and Composition and Adding Dyes

Nine combinations each of HNO_3 and NH_4OH were created. Because certain compounds, such as TiO_2 and PEG, make foams more flexible and quicken the gelling process, 1-mL samples of different combinations and concentrations of HNO_3, NH_4OH, TiO_2, PEG, and dyes were tested.[11] Small pieces of Styrofoam were added to the solution to see how well the foam would act as a coating.

Figure 7: Sample from the second set of foam tests after 23 hours of drying. NH_4OH; TiO_2, PEG, and Yellow Food Dye foam with a small piece of Styrofoam

3.2.2.1. Staining Procedure

The Styrofoam pieces from the dyed foams were placed into the dye solution from the Filtration Procedure. After letting the foams soak all night, the abilities of the foams to prevent staining were observed.

3.2.3. Reinforcing Integrity

For the third round of testing, different polymers were used to reinforce the structural integrity of the foams. White string, Hollo-W polymer (gold), Quill-50 polymer (black), and clear polypropylene polymers were cut into lengths from 1 to 2 cm. 3 mL of a prepared solution were poured into a small Petri dish, the cut-up pieces of a polymer were added, and 3 mL, again, of the solution were poured on top. This process was repeated for a total of three prepared solutions:

- 15 mL of sol, 15 mL of NH_4OH, 0.7171 grams of TiO_2, 1.5830 grams of PEG
- 15 mL of sol, 15 mL of HNO_3, 0.6938 grams of TiO_2, 1.5830 grams of PEG
- 15 mL of sol, 50 mL of NH_4OH

The properties of these foams were tested, and each sample was split in half. A nail polish coating was applied to the foams, and then their strength and solubility were tested. The foams were ranked by how many fractures there were in the foam, and the solubility was tested by timing how long it took for the foam to dissolve.

Figure 8: Polymers in sol after 24 hours of drying

3.3. DEVELOPING THE COATINGS

3.3.1. Creating the Absorbent Rim

50 mL of the sol were poured into a 200-mL Erlenmeyer flask. The flask was covered with aluminum foil and allowed to settle. The 50 mL of the solution were poured from the Erlenmeyer flask into a 150-mL beaker. 2 mL of TiO_2 and of PEG were added to the 150-mL beaker. Using a pipette, half a drop of yellow food coloring was stirred in until there were no clumps in the solution.

3.3.2. Creating the Mold for the Rim

Three different methods were used to create the mold:

- A large Petri dish was filled with sol. The Styrofoam cup was placed upside-down in the solution and left overnight to dry.
- A small Petri dish was glued with neutral pH glue onto the middle of a large Petri dish with the bottom of the small Petri dish facing upwards as seen in Figure 10. The solution in the beaker was carefully poured into the large Petri dish, forming a ring around the small Petri dish.

Figure 9: Using the small and large Petri dish combination to coat the rim of a Styrofoam cup

- A 1-ft^2 sheet of plastic wrap was placed over a Petri dish and pressed down to eliminate all air bubbles. The rim of the Styrofoam cup was placed around the small Petri dish onto the large Petri dish within the plastic wrap, without touching the circumference of the dish.

These molds were allowed to solidify overnight and were removed 22-24 hours later.

3.3.3. Adding the Leuco Dye

A batch of mood rings was tested for heat sensitivity. The mood rings that readily changed with temperature were crushed using a mortar and pestle. The remaining metal portion had exposed leuco dye. The metal piece was then secured onto the cup so that the dye from the ring would get onto the foam coating for the cup's body.

3.3.4. Coating the Body of the Cup

Two different solutions were tested for the coating of the cup's body:

- Basic formula: 15 mL of sol, 15 mL of NH_4OH, 0.7171 g of TiO_2, 1.5830 g of PEG
- Acidic formula: 15 mL of sol, 15 mL of HNO_3, 0.6938 g of TiO_2, 1.5830 g of PEG

60 mL of each solution were created. Ten 30-cm lengths of white string were cut. Five of those were further cut into lengths from 1 to 2 cm. The neutral pH glue was painted onto one Styrofoam cup, and the 1-2-cm pieces of string were sprinkled along the outside. Another coat of glue was put on top of the string. For the second cup, the 30-cm lengths of string were dipped in glue. The string was wrapped around the Styrofoam cup in a crisscross fashion.

Two methods were used in applying the foam coat to the Styrofoam cup. Initially, a large metal coffee can was used. The can was filled with a solution, and the Styrofoam cup was placed into the can. The can was too large and required too much sol to coat the entire cup.

Instead, a small aluminum disposable Petri dish was inverted inside of a large paper cup. The sides of the aluminum disposable Petri dish were pushed against the edge of the paper cup. One of the two solutions was added to the paper cup. The first Styrofoam cup was placed into the paper cup and left to dry over the weekend. This procedure was repeated for the second Styrofoam cup. A clear coat of nail polish was applied after the foam dried.

4. RESULTS AND OBSERVATIONS

4.1. Properties of Foams Results

Qualitatively, the best gels were the gels catalyzed by HNO3 and by NH4OH because although those two were brittle, the other eight were too powdery to act as a coating on a Styrofoam cup (see Appendix: Table 1).

4.1.1. Density Observations

Many of the foams formed from the salt catalysts were too porous to take accurate density measurements. Of the foams that maintained structural integrity, the order from most dense to least dense is: NH_4OH, $CoCl_2$, NaCl, $CoCl_2$ + NaCl + NH_4OH, HNO_3.

4.1.2. Absorbency Observations

The foams disintegrated more quickly in the water than in the ethanol. The NaCl foam dissolved and turned the water into a milky white color with many particulates. The HNO_3 foam splintered and cracked within a minute of contact with water, also turning transparent. The $CoCl_2$ + NaCl + NH_4OH foam disintegrated into a fine powder.

The aerogel demonstrated the most absorbency and retained its structural integrity.

4.1.3. Heat Capacity Observations

The HNO_3 and the NH_4OH foams demonstrated the most heat capacity and were relatively good insulators.

4.1.4. Filtration Observations

The aged sol + HNO_3 + TiO_2 + PEG foam acted as the best filters. The blue and yellow dyes were absorbed in highest quantities.

Figure 10: The dye-trapping abilities of the aged sol-gel

4.1.5. Scanning Electron Microscope

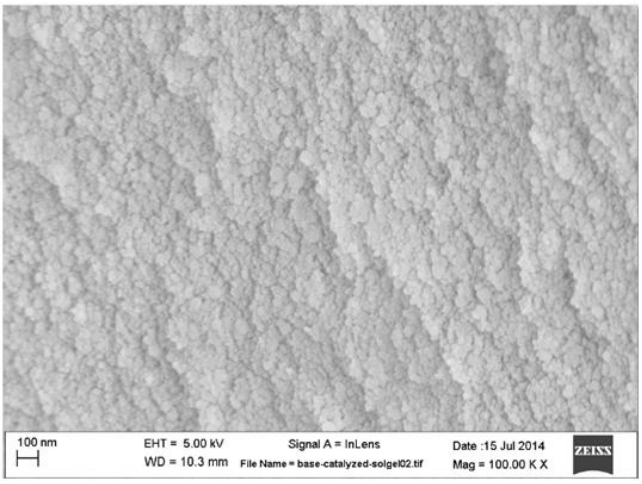

Figure 11: Scanning electron microscope image of a base-catalyzed (NH_4OH) gel

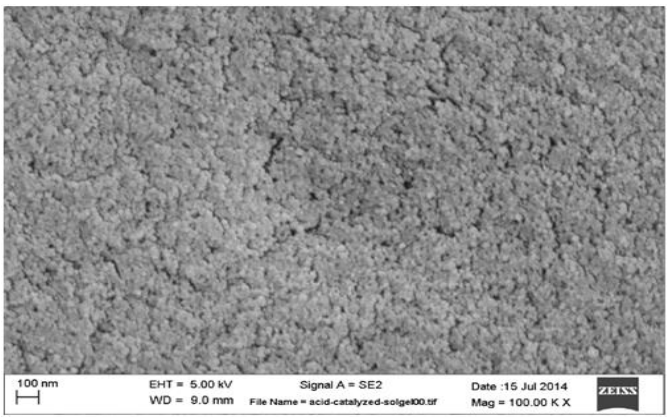

Figure 12: Scanning electron microscope image of an acid-catalyzed (HNO_3) gel

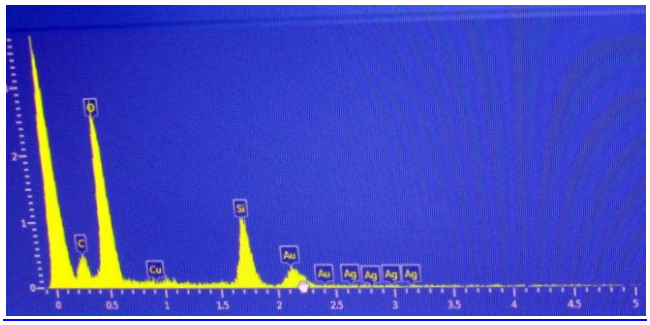

Figure 13: The composition of the acid-catalyzed gel

4.2. FUNCTION OF COATINGS

4.2.1. Variation of Concentration and Composition

The three strongest combinations of sol, HNO_3 or NH_4OH, TiO_2, PEG, and dye were (see Appendix: Table 2):

- 15 mL of sol, 15 mL of NH_4OH, 0.7171 g of TiO_2, 1.5830 g of PEG
- 15 mL of sol, 15 mL of HNO_3, 0.6938 g of TiO_2, 1.5830 g of PEG
- 15 mL of sol, 50 mL of NH_4OH

Figure 14: Dried samples from the second round of synthesizing gels by altering concentration and composition and adding dyes

4.2.2. Reinforcement of Integrity

The white string held the gelled product together well in the solution of sol, NH_4OH, TiO_2, and PEG, and in the solution of sol, HNO_3, TiO_2, and PEG (see Appendix: Table 3).

Figure 15: Dried samples from the third round of synthesizing gels by adding polymers

4.2.3. Formation of the Coating

The best way to coat the rim was the method of gluing a small Petri dish onto a large Petri dish.

The longer pieces of white string held the foam together better than the shorter pieces.

The HNO_3 coating attached better to the Styrofoam cup than the NH_4OH coating.

Figure 16: Styrofoam cup with absorbent rim and insulating coating

5. DISCUSSION

Throughout the entire process, the team's approach to the project went through many revisions. Various combinations of chemical compounds to create foams were tested, and multiple methods of coating the Styrofoam cup were tried. It was determined that the combination of chemical compounds best suited to coat the rim of a Styrofoam cup was 50 mL of sol, 2 mL of TiO_2, and 2 mL of PEG. TiO2 increases the flexibility of the gel, and PEG decreases the drying time of the gel. Every gel synthesized contained PEG in order to quicken the drying process so that a successful prototype could be completed within the limited time frame. As a result, the chemical combination of sol, TiO_2, and PEG was used for the rim because it produced the strongest absorbent gel. However, on many occasions, the gel would shrink and crack as it dried, and the coating would crumble off the cup.

The best combination for the rest of the cup was 60 mL of sol, 7 mL of HNO_3,

2.7752 g of TiO_2, and 3.2000 g of PEG. This combination was used as opposed to the NH_4OH mixture because the combination containing the HNO_3 was more porous (Figure 12). This makes sense as acid-catalyzed gels form long polymer chains, so the pores between the chains are uniform. The HNO_3 also stuck well to the Styrofoam cup. Therefore, because the HNO_3 gel was more porous, it was a better thermal insulator, and it was as strong as the NH_4OH gel, it was used for the coating.

6. CONCLUSION

The aim of this project was to test the properties of different gels in order to find the optimal gel to enhance a Styrofoam cup's use. These properties include strength, insulation, sensitivity to heat, and hydrophilicity – the rim of the cup was made hydrophilic to prevent spilling as the coating on the rim would absorb the spillage. The rest of the cup was coated with a chemically modified gel which had the other listed ideal properties. Overall, the goal of the project was achieved because the foam coatings provided the desired material properties. However, during the process of coating the Styrofoam cup, the team had several prototypes. A major reason for this was that due to time limitations, the methods and experiments performed for this project were not perfect, as one of the drawbacks to using the sol-gel process is that it takes a substantial amount of time to create high-quality gels. Consequently, the simplest way to improve this project would be to perform it over a longer period of time to obtain more results and higher-quality gels. Additionally, in the final prototype, the leuco dye did not successfully attach to the cup, so another improvement that could be made is to find a better adhesive for the dye. In the future, the team would also address the disposability of the cup. Once used, the rim would absorb water and therefore could not be used again. A reusable cup would be more efficient.

The project's objective of using the gel as a coating could be applied to several other studies. The simplest advancement of this project would be to apply the coating to other kitchenware that could potentially burn people. Not only cups but also pots, pans, and other containers could be coated with this same gel in order to give them enhanced strength and make them heat-indicative. Furthermore, by taking advantage of all the properties of the gel, such as its porosity, it could be used as a filter for dirty water. Because the gel is a good insulator, it can also be used as a coating on buildings. Although there is room to grow, what has already been accomplished in this project has the potential to improve existing foam technology.

Acknowledgements

The authors would like to acknowledge their project mentor, Dr. Lisa C. Klein, for invaluable guidance and access to the Sol-Gel Processing Laboratory. They would like to extend their thanks to their advisor, Edmund Han, for organizing the project and revising the team's work. The authors would like to mention graduate students James Davanzo, Eleni Temeche, and Chau Tran for supervising and helping in the laboratory. Additionally, the authors appreciate the generosity of Dr. Sukanya Murali, for the opportunity to work with the scanning electron microscope. Finally, the group would like to thank Deans Ilene Rosen and Jean Patrick Antoine, the director and assistant director of Governor's School for Engineering and Technology, and the other organizers of the program for the opportunity to do this research, as well as its sponsors: Rutgers University; the State of New Jersey; Jersey South Industries, Inc.; Lockheed Martin; Morgan

Stanley; Novo Nordisk; Provident Bank Foundation; and Silver Line Windows.

References

[1]Bertram, Bonnie. "Storm Still Brews over Scalding Coffee." *The New York Times*. New York Times, 25 Oct. 2013. Web. 15 July 2014. <http://www.nytimes.com/2013/10/28/booming/storm-still-brews-over-scalding-coffee.html?_r=0>.

[2]"Burn-Relate Injury/Death Statistics." *TOMA Foundation for Burned Children*. TOMA Foundation for Burned Children, n.d. Web. 19 July 2014. <http://www.fondtomafound.org/frenchnew/articles/burninjury.htm>.

[3]"What Is Nanotechnology?" *Nano.gov*. National Nanotechnology Initiative, n.d. Web. 17 July 2014. <http://www.nano.gov/nanotech-101/what/definition>.

[4]"Colloids." *ChemWiki*. UC Davis, n.d. Web. 17 July 2014. <http://chemwiki.ucdavis.edu/Physical_Chemistry/Physical_Properties_of_Matter/Solutions_and_Mixtures/Colloid>.

[5]Klein, Lisa C. "Sol-Gel Processing." PowerPoint presentation. Rutgers University, Piscataway, NJ. 1 July 2014.

[6]"Thermochromic Technology." *LCR Hallcrest*. LCR Hallcrest, n.d. Web. 15 July 2014. <http://www.colorchange.com/thermochromic>.

[7]"Thermochromic Leuco Dyes." *LCR Hallcrest*. LCR Hallcrest, n.d. Web. 15 July 2014. <http://www.colorchange.com/leuco-dyes>.

[8]Iliev, Oleg. "Optimization of Insulation Materials." *Fraunhofer ITWM*. Fraunhofer Institute for Industrial Mathematics ITWM, n.d. Web. 17 July 2014. <http://www.itwm.fraunhofer.de/en/departments/flow-and-material-simulation/hydrodynamics/insulation-materials.html>.

[9]Hegde, Raghavendra R., M. G. Kamath, and Atul Dahiya. "Absorption Properties." *Materials Science & Engineering* 554. Larry C. Wadsworth, Apr. 2004. Web. 17 July 2014. <http://www.engr.utk.edu/mse/Textiles/Absorption.htm>.

[10]Klein, Lisa C. "Porosity." PowerPoint presentation. Rutgers University, Piscataway, NJ. 3 July 2014.

[11]Lenza, Rubio F. S., and Wander L. Vasconcelos. "Synthesis of Titania-Silica Materials by Sol-Gel." *Materials Research* 5.4 (2002): n. pag. *Scientific Electronic Library Online*. Web. 19 July 2014. <http://www.scielo.br/scielo.php?pid=S1516-14392002000400017&script=sci_arttext>.

Appendix

Table 1: Qualitative Observations of the Effect of Various Catalysts in the Sol-Gel Process

Foam Type	Description
HNO_3 (low concentration)	• Cloudy, as though the sol and the HNO_3 were clearly separate • HNO_3 formed a thin film on the surface of the sol • Broke apart easily when the sol dried into a gel
HNO_3 (high concentration)	• Very white • Bumpy surface • Brittle
NH_4OH (low concentration)	• Viscosity similar to that of water • Took a long time to dry into a gel • When dry: texture like glass, easily breakable, and opaque white rather than transparent
NH_4OH (high concentration)	• When drying: split into large shards • When dry: porcelain-like texture • White
NaCl (10w concentration)	• Became increasingly viscous with more salt, and surface tension increased • Pasty consistency, as though it was very soft rice, and it was an opaque white • NaCl clumped together initially
NaCl (high concentration)	• Quickly began to congeal and form small clumps
$CaCl_2$ (low concentration)	• Very similar to the solution of sol and NaCl
$CaCl_2$ (high concentration)	• White • Formed large clumps
$CoCl_2$ and NaCl	• Turned a pasty blue-purple
$CoCl_2$, NaCl, and NH_4OH	• Consistency similar to that of toothpaste gel
$CoCl_2$, $CaCl_2$, and NaCl	• Very hard • Formed numerous small clumps • Mostly white with spots of blue

Table 2: Qualitative Observations from the Additions of TiO2, PEG, and Dyes

Foam Type	Description
HNO_3 in a 1:3 sol-to-additive ratio	• Somewhat chalk-like in texture
HNO_3 in a 1:1 sol-to-additive ratio	• Gel was relatively solid • Split into large shards of ceramic-like gel
HNO_3 in a 3:1 sol-to-additive ratio	• Gel was brittle and broke easily
NH_4OH in a 1:3 sol-to-additive ratio	• Gel was hard • Fractured into large chunks
NH_4OH in a 1:1 sol-to-additive ratio	• Very hard, smooth ceramic-like texture
NH_4OH in a 3:1 sol-to-additive ratio	• Brittle • Many small shards
HNO_3, TiO_2, PEG, and blue food coloring	• Bumpy texture • Somewhat hard to break
HNO_3, TiO_2, PEG, and yellow food coloring	• Bumpy texture • Somewhat hard to break
HNO_3, TiO_2, PEG, and red food coloring	• Bumpy texture • Somewhat hard to break
HNO_3, TiO_2, PEG, and fluorescein	• Turned a light pink color • Stayed mostly intact.
NH_4OH, TiO_2, PEG, and blue food coloring	• Fractured into small shards
NH_4OH, TiO_2, PEG, and yellow food coloring	• Fractured into small shards
NH_4OH, TiO_2, PEG, and red food coloring	• Fractured into small shards
NH_4OH, TiO_2, PEG, and fluorescein	• Fluorescein did not dissolve into the sol very much • Solidified with small chunks of dye still embedded • Stayed mostly intact.

Table 3: Qualitative Observations from the Addition of Polymers to NH_4OH and HNO_3

Foam Type	Description

NH_4OH, TiO_2, and PEG; and clear polypropylene	• Polypropylene floated to the top and hardened into a gel that way
NH_4OH, TiO_2, and PEG; and black Quill-50 polymer	• Quill-50 polymers floated to the edges of the Petri dish
NH_4OH, TiO_2, and PEG; and gold Hollo-W polymer	• Hollo-W polymers clung to each other and floated to the top
NH_4OH, TiO_2, and PEG; and white string	• String sunk to the bottom
HNO_3, TiO_2, and PEG; and clear polypropylene	• Sol solidified into a paste-like gel that was like chalk in its texture
HNO_3, TiO_2, and PEG; and black Quill-50 polymer	• Sol solidified into a paste-like gel that was like chalk in its texture
HNO_3, TiO_2, and PEG; and gold Hollo-W polymer	• Sol solidified into a paste-like gel that was like chalk in its texture
HNO_3, TiO_2, and PEG; and white string	• Sol solidified into a paste-like gel that was like chalk in its texture
NH_4OH; and clear polypropylene	• Did not solidify completely
NH_4OH; and black Quill-50 polymer	• Did not solidify completely
NH_4OH; and gold Hollo-W polymer	• Did not solidify completely
NH_4OH; and white string	• Did not solidify completely