**Novel Thermal Conductivity Measurement Technique for Aeroclay**

**Abstract**

This proposal is addressed to Case Western Reserve University professors Dr. Alexis Abramson, of the nanoEngineering Laboratory, and Dr. David Schiraldi, inventor of aeroclay and founder of Aeroclay Incorporated, requesting laboratory space to perform experiments and funding in the amount of $5117.65 for materials necessary to perform the experiments. Aeroclay is new insulative material with unknown thermal conductivity and is an environmentally friendly and cheaper replacement for aerogel. Even though its thermal conductivity is unknown, it is known that aeroclay has one of the lowest thermal conductivities of currently available materials, and as such, is a very good insulator. It is made from water, clay, and polymers and is synthesized through a freeze drying process. There currently does not exist an available method to determine the thermal conductivity of aeroclay, and this proposal fulfills that need. A technique can be created within one fifteen week semester that will be able to accurately and precisely determine the thermal conductivity of aeroclay based on Fourier’s law. This proposal will allow Dr. Schiraldi’s laboratory group to continue working on aeroclay and will increase the marketability of aeroclay as a commercial product. Aeroclay has the potential for many uses including use as insulation on a refrigerated truck or many aerospace applications as it is extremely lightweight.

**Project Description**

I propose creating a novel technique to determine the thermal conductivity of aeroclay. Aeroclay is a relatively new material that was created at Case Western Reserve University in the Department of Macromolecular Science and Engineering by Professor David Schiraldi and is still being researched. Aeroclay is an insulative material (e.g. it has a low thermal conductivity). To be able to determine how insulative the aeroclay materials are, a method is needed to measure the thermal conductivity of the materials. Currently, a method to measure the thermal conductivity of materials with such low conductivities does not exist. Because the optimum formula to make aeroclay is still being determined, the thermal conductivity of each formula of aeroclay needs to be tested to direct the work of the macromolecular researchers. Aeroclay is an environmentally safe replacement for aerogel. There is a significant cost advantage of using and manufacturing aeroclays instead of using and manufacturing aerogels. Aeroclay has the potential for use in refrigerator trucks as well as aerospace applications.

**Literature Review (Background)**

The purpose of this literature review is to investigate aeroclay and previous research on techniques used to determine the thermal conductivity of materials. Aerogels and aeroclays are both insulative materials and have similar insulative properties. The literature review will have a focus on aerogel, which aeroclay was designed to replace, and the advantages of aeroclay over aerogel.

**Introduction**

Aerogels are inorganic materials composed of mostly air (Bandi, 2005, p. 1). Aerogels typically have densities in the range of 0.01 g/cm3 to 0.1 g/cm3 (Bandi, 2005, p. 1). In most cases, aerogels are composed of silica (Bandi, 2005, p. 1). These silica aerogels have thermal conductivies on the order of 0.01 W/m2\*K (Lu, 1992, p. 1). To put this value into perspective, fiberglass insulation has a thermal conductivity of 0.79 W/m2\*K and copper, a very good thermal conductor, has a thermal conductivity of 401 W/m2\*K. Thermal conductivies of this order are some of the lowest of currently available materials, and because of this property, are very good insulators. Aeroclays have densities in the same range as aerogels and have similar insulative properties (Schiraldi, 2008, p. 3). Instead of silica, aeroclays are composed of water, clay, and polymers (Schiraldi, 2008, p. 3).

At Case Western Reserve University, work is being done under Professor David Schiraldi on aeroclay. Through his research, Professor Schiraldi founded Aeroclay Inc in 2010 to continue the process of commercializing aeroclay (Aeroclay, 2010, p. 1).

**Health and Manufacturing Issues with Aerogel**

Aerogels are frequently made of silica, and silica has many adverse health effects. Silica is known to be a carcinogen (Slivka, 2005, p. 1). Exposure to silica dust has been associated with an increased risk of silicosis, tuberculosis, chronic bronchitis, chronic obstructive pulmonary disease, and lung cancer (Merget, 2001, p. 1). With health issues this severe, there is a great need to replace aerogel with another material. Changing from aerogel to aeroclay will protect countless people from those who work in manufacturing the material to the end users of the material.

In addition to the health issues that exist in regard to aerogel, there are also problems relating to the manufacturing process of the materials. Numerous chemicals, in significant amounts, are used in the manufacturing of aerogel. To allow aerogels to be largely composed of air, supercritical drying is used to remove liquid from the material during synthesis (Gurav, 2010, p. 2). The process of supercritical drying involves using large amounts of solvents. The process is time and labor intensive resulting in a high cost to produce aerogels.

**Advantages of Aeroclay over Aerogel**

The density and thermal conductivity ranges are the same for aeroclay and aerogel, but aeroclays are better than aerogels in several ways. First, aeroclays are composed of clay, water, and polymers (Schiraldi, 2005, p. 3). There are no adverse health effects from these materials unlike silica, which has severe health issues (Hostler, 2009, p. 1). Another benefit of aeroclay as opposed to aerogel is the method used to synthesize the materials. Aeroclays are made through freeze-drying, which eliminates the need for chemicals such solvents that are used in the process of synthesizing aerogels (Hostler, 2009, p. 1). During the freeze-drying process, water sublimes, eliminating the need for the use of solvents and supercritical drying (Hostler, 2009, p. 2). Since solvents are not used in the manufacturing of aeroclays, aeroclays cost less to produce than aerogels.

**Research on Thermal Conductivity Techniques**

Knowing the thermal conductivity of a material is frequently vital. In the case of a refrigerated truck, knowing the thermal conductivity of the insulation allows for the correct sizing of the refrigeration unit on the truck. As such, much research has been done on developing techniques to determine thermal conductivity of different materials of many different shapes and sizes. Recently, under the direction of Professor Alexis Abramson of Case Western Reserve University’s Department of Mechanical and Aerospace Engineering, the nanoEngineering Laboratory developed a novel technique for determining the thermal conductivity of thin graphite materials (Mahanta 5585). The nanoEngineering Laboratory has also developed a new technique to measure the thermal conductivity of carbon nanofiber mats (Mahanta, 2010, p. 4457). Unfortunately neither of these techniques are applicable in determining the thermal conductivity of an aerogel or aeroclay. One of the reasons is that the size and shape of an aeroclay will not fit within the experimental setup of the nanoEngineering Laboratory’s techniques. Also, due to the size and shape, the aeroclay would violate some of the assumptions that are an integral part of the techniques.

**Conclusion**

Existing research on thermal conductivity measurements has shown that there are no available methods to determine the thermal conductivity of an aeroclay. Aeroclays provide the same performance as aerogels, but aeroclays are cheaper to produce and are safer to the people involved with manufacturing or using the materials.

**Research Plan**

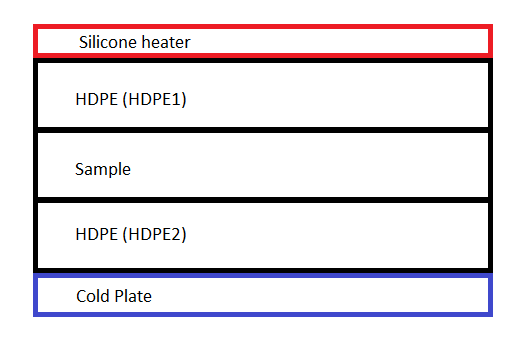
The novel technique to determine the thermal conductivity of aeroclay is based on Fourier’s law, which is, where q is the heat flux, k is the thermal conductivity, A is the area of the material, ΔT is the temperature change across the material, and Δx is the thickness of the material. As seen in figure 1, the setup will consist of a cold plate attached to a liquid chilling system on the bottom, a piece of high density polyethylene above the cold plate (labeled HDPE2), the sample above HDPE2, another piece of HDPE (labeled HDPE1) above the sample, and a silicone heater on top. The cold plate will function to cause the cold plate and the temperature of the bottom of HDPE2 to be at a constant temperature selected by experimentation to optimize performance. HDPE1 and HDPE2 are one half inch thick. The silicone heater is to be connected to a Starco Energy Products power supply. There will be four thermal couples to record temperatures located in the setup: one between the silicone heater and HDPE1, one between HDPE1 and the sample, one between the sample and HDPE2, and one between HDPE2 and the cold plate. These four thermal couples are to be attached to an Omega Data Logger thermometer, which is, in turn, to be plugged into a computer via a USB cable.

Figure : Side view of testing setup

The aeroclay samples from Dr. Schiraldi’s lab are 4 inches square, 5 inches square, and 6 inches square. To accommodate for this, from a bulk piece of HDPE, two pieces of those three sizes will need to be made in a machine shop. Also, a piece of HDPE, PEEK, and polycarbonate (all three materials are polymers that have low thermal conductivities) will need to be machined to 6 inches square. All three materials need to be one half inch thick in order to simplify calculations.

During the initial testing phase of the project, from week 3 through week 12, HDPE will be placed where the sample is in figure 1. The goal of the initial testing is to have the average of the temperature change across HDPE1 and HDPE2 be the same as the HDPE in the sample position. It is extremely important that the thicknesses of all three pieces of HDPE be the same or more complicated calculations will need to be performed instead of using this simple calculation. The pieces of HDPE also need to be 6 inches square to use this calculation. This calculation uses a simplified version of Fourier’s law where, when area, thickness, and thermal conductivity are all the same, the only factor that matters is the change in temperature.

There are issues of heat loss through the sides of the setup and contact resistance between the materials that will have to be eliminated. These issues will be eliminated through the use of fiberglass insulation around the sides of the apparatus, pressure being put on the top of the setup, changing the amount of heat coming from the heater, changing the temperature of the chiller system, and the use of thermal paste between HDPE1 and the sample, the sample and HDPE2, and HDPE2 and the cold plate. Two weeks are set aside in the schedule to determine exactly how to use these five items to eliminate the issues. Specifically, for the insulation tests, experiments will be run with the fiberglass insulation oriented in different directions and with different amounts of fiberglass around the setup among other changes with the insulation. For the pressure tests, pressure will be applied to the top of the setup in differing amounts until the amount giving the optimum results is found. For the thermal paste tests, different amounts of thermal paste will be applied, and the optimum amount of thermal paste will be determined. For the heat and chiller tests, the temperature of both will be changed independently until the optimum temperature for each is determined.

After the initial testing is complete, the verification testing will begin with PEEK and polycarbonate. The calculation to determine the thermal conductivity of the sample is the same whether the thermal conductivity is known, such as when verification tests are being run on PEEK or polycarbonate, or when the thermal conductivity is not known, such as when an aeroclay is being tested. The calculations are the following. First, the heat flux through HDPE1 and HDPE2 are found using Fourier’s law. Then, the two heat fluxes are averaged. This number is then used in Fourier’s law along with the dimensions of the sample and the temperature change across the material. Fourier’s law can then be solved to give the conductivity of the sample.

Once it is shown, for both PEEK and polycarbonate, that the thermal conductivity can be accurately determined, the setup is ready for use to determine thermal conductivity of aeroclays. PEEK and polycarbonate are selected for verification purposes in this project because the thermal conductivities of both materials are available in engineering handbooks.

In the research schedule, below, it may seem like two weeks is a long time for each stage of the initial testing section. A calculation using the thermal equivalent of the Navier-Stokes equations reveals that the tests will take approximately 12 hours to run, which means, in a two week period, at most, 14 experiments can be run. Fourteen tests should be enough for each stage of the initial testing section.

**Research Schedule**

Below is the schedule for the research which is expected to take one fifteen week semester to complete:

Week 1: Acquire all necessary equipment and bulk materials

Week 2: Assemble chiller system, machine reference and verification materials

Weeks 3-12: Initial testing

Weeks 3-4: Insulation tests

Weeks 5-6: Pressure tests

Weeks 7-8: Thermal paste tests

Weeks 9-10: Heat tests

Weeks 11-12: Chiller system tests

Weeks 13-14: Verification Testing

Week 15: Begin testing of aeroclay

**Personal Qualifications**

I have much experience working in a laboratory setting.  This past summer, I worked in a research lab at NASA Glenn Research Center testing different properties of several polymer-based materials.  From May 2009 through January 2010, I took part in a project to determine the thermal conductivity of carbon microtube materials, in the nanoEngineering Laboratory.  From my laboratory experience I have learned to use many pieces of equipment including thermal couples, thermal couple readers, and the associated software. I also know about protocols and procedures for conducting research in a lab. Additionally, I know how to requisition materials and equipment necessary for conducting research.

As part of my coursework at Case Western Reserve, I took Mechanical Manufacturing. During the lab portion of this course, I learned how to use equipment in a machine shop. These skills will be very useful for me in this project as they will allow me to machine materials myself.

**Budget**

The following budget was generated using prices from McMaster-Carr and Omega Engineering. Both of these companies supply most of the needs of laboratories in the Department of Mechanical and Aerospace Engineering at Case Western Reserve University.

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| **Non-consumable** | |
| *Item* | *Cost* |
| Omega Data Logger Thermometer (HH309A) | $299.00 |
| Thermocouples (5TC-TT-K-40-36), 2 pkg. | $120.00 |
| Starco Energy Products Power Supply (3PN221B) | $450.00 |
| Square silicone heaters (6” sq, 5” sq, 4” sq) | $102.00 |
| High density polyethylene | $52.48 |
| PVC | $3.45 |
| PEEK | $165.25 |
| Polycarbonate | $35.17 |
| Steel plates, 4 | $66.72 |
| Dell computer | $750.00 |
| *Cooling system:* | |
| Copper cold plates (35035K32), 2 | $109.32 |
| Low-Temperature Circulating Chiller (3538K66) | $2841.19 |
| Fiberglass insulation (9346K38) | $32.07 |
| **Consumable** | |
| *Item* | *Cost* |
| High Conductivity Thermal Paste (OT-201-2) | $75.00 |
| Nitrile Gloves, 200 ct. | $16.00 |
| **Total:** | **$5117.65** |

**Anticipated Involvement**

For this project, I need laboratory space in either the nanoEngineering Laboratory or in Dr. Schiraldi’s laboratory to perform the research. I also need to be funded $5117.65 as outlined in the budget section to purchase all of the necessary equipment. The workload is not particularly high for this project so I will be able to perform all of the work and research myself.

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