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NUCLEAR THERMAL SOURCE TRANSFER UNIT, POST-BLAST SOIL SAMPLE DRYING SYSTEM

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Los Alamos National Laboratory states that its mission is “To solve national security challenges through scientific excellence.” [2] The Science Undergraduate Laboratory Internship (SULI) programs exists to engage undergraduate students in STEM work by providing opportunity to work at DOE facilities. [5] As an undergraduate mechanical engineering intern under the SULI program at Los Alamos during the fall semester of 2016, I had the opportunity to contribute to the mission of the Laboratory while developing skills in a STEM discipline. I worked with Technology Applications, an engineering group that supports non-proliferation, counter terrorism, and emergency response missions. This group specializes in tool design, weapons engineering, rapid prototyping, and mission training. I assisted with two major projects during my appointment Los Alamos. The first was a thermal source transportation unit, intended to safely contain a nuclear thermal source during transit. The second was a soil drying unit for use in nuclear post-blast field sample collection. These projects have given me invaluable experience working alongside a team of professional engineers. Skills developed include modeling, simulation, group design, product and system design, and product testing.

Keywords: Thermal Source; Passive Cooling; SolidWorks Flow; Nuclear Post-Blast Response; Soil Sample Processing; Soil Drying

I. THERMAL SOURCE TRANSFER UNIT

A. Project Description

The goal of the first project was to create an enclosed container to be used in transporting a nuclear thermal source. The initial assignment included several goals: The unit should be able to contain a heat source up to sixteen inches in diameter, and should be collapsible for compact storage. The main challenge to transporting a thermal source is overheating, so the unit should have the capacity to keep the heat source below 120°F. It should be filled with an inert gas during transit—preferably helium—both for increased thermal transfer and to prevent oxidation or fires inside the container. The system should be able to maintain the goal temperature for at least eight hours, and it should weigh less than 120 pounds for easy handling. Finally, the unit should actively monitor the internal conditions of the system, including temperature and pressure, and display this information to the operators.

The material density of the nuclear thermal source is 3.5 g/cc, and its heat power ratio is approximately 30 W/Kg. These relationships imply that a spherical source just ten inches in diameter can produce 900 Watts of heat power. (Although the power output of the source is a cube function proportional to the volume, for our simulations we capped the power output to 1000 Watts, as this is the realistic maximum output expected from this material at this size. See FIG 1.) As a demonstration of the magnitude of this heat power, we expect a thermal source of twelve-inch diameter, in a room temperature environment, to reach thermal equilibrium near 300°F. In the field, the transfer unit may have to accommodate various shapes of heat sources. However, for our simulations we simplified the problem by considering spherical heat sources. FIG 1 shows the power output for a range of heat source sizes from 4 inches to our maximum, sixteen inches.

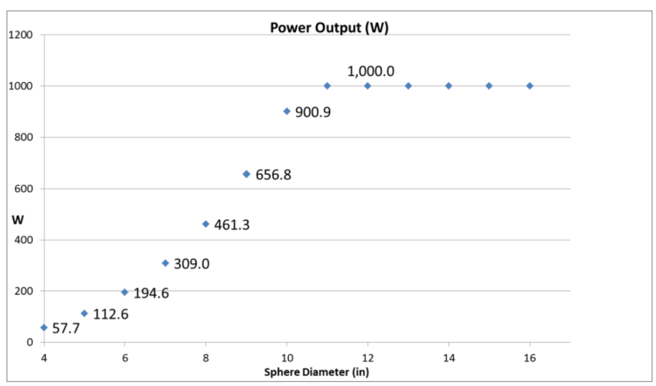

FIG 1: Note the cubic rise, followed by power capping at 1000W.

B. Design Process

All of our design ideas focused on cooling the heat source. Our first ideas centered on developing an active cooling system. The initial design concept consisted of a collapsible aluminum box to enclose the heat source, and an air conditioning unit or comparable refrigeration system to cool the gas inside the enclosure. Any small household air conditioner, for example, could be modified to provide the adequate cooling power required. One thousand Watts is approximately 3400 BTU/hour, and most small AC units provide at least 5000 BTU/hour. However, on further thought, we decided to explore passive cooling systems. While passive cooling systems may be less effective in terms of absolute cooling power than active cooling systems, the advantages of passive cooling lend themselves to our project. In general, passive cooling systems are lower-maintenance, provide more consistent results, and are longer lasting than active cooling designs. They usually involve no moving parts susceptible to failure. Because our unit might be used in remote or harsh locations, we wanted to avoid using a large power source and the bulky radiators, compressors, and fans that active air cooling systems usually involve.

To simulate the heat transfer characteristics of our designs we used SolidWorks Flow. This is a computational fluid dynamics add-in to SolidWorks, an industry standard mechanical 3D modeling and simulation software. To better understand the problem, we simulated enclosing a ten-inch heat source in an aluminum box, resting on an insulating floor, with all gasses and solids beginning at room temperature (68°F, 293K). When this simulation reached thermal equilibrium, the temperature of the heat source was 412K (282°F), a similar outcome to the result of placing the same heat source in open air. One important conclusion drawn from this simulation was the importance of allowing the heat source to contact the exterior walls of the container. Helium, with thermal conductivity of 0.138 W/mK at 20°C, is about six times more thermally conductive than air; however, heat transfer by convection and conduction through this gas is vastly less efficient than conduction through the aluminum, as its thermal conductivity is 205.0 W/mK. [6]

To understand heat conduction in this problem, it is useful to study the equation for thermal conduction through a plane wall. [1]

Equation 1: Conduction through a plane wall

$$W = \frac{\lambda \, A \, \Delta T}{s}$$

$$Where\ \lambda = thermal\ conductivity; A = area;$$
$$\Delta T = \ temperature\ differential;\ s = wall\ thickness$$

We can apply this formula to the aluminum enclosure. If it is a twenty-four inch cubic box, one quarter of an inch thick, and if the temperature differential is 11K (20°F), the walls have the capacity to conduct almost 800,000 Watts. This calculation implies that if the heat source contacts the exterior walls of the device, it should be able to quickly conduct heat to the environment.

While we realized that contact with the exterior would be essential to heat transfer, we knew that the size and shape of the heat sources is variable. This observation leads to the main disadvantage of the cube box design: it does not allow many different sizes of objects good contact with the exterior walls. Our subsequent brainstorming focused on creating a design that would allow any heat source to contact the exterior at multiple points.

After several design iterations and hundreds of simulations, we chose a cone-shaped design. Because its diameter varies with height, any size object placed inside must contact the exterior walls. This contact is aided by aluminum foil packed around the object, to help provide a thermal pathway to the exterior heat sinks. To assist natural convection across the exterior fins, we added a small fan at the base to force air up and around the device.

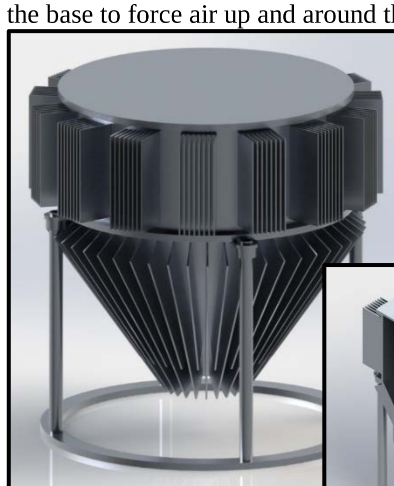

FIG 2: Final concept, with eight-inch spherical heat source for visualization.

The item disassembles in sections, in accordance with the project goals, and the largest section is the tapered shell, with a twelve inch height and a twenty inch diameter. Gaskets between sections prevent helium leakage, and cam levers clamp the sections together during use.

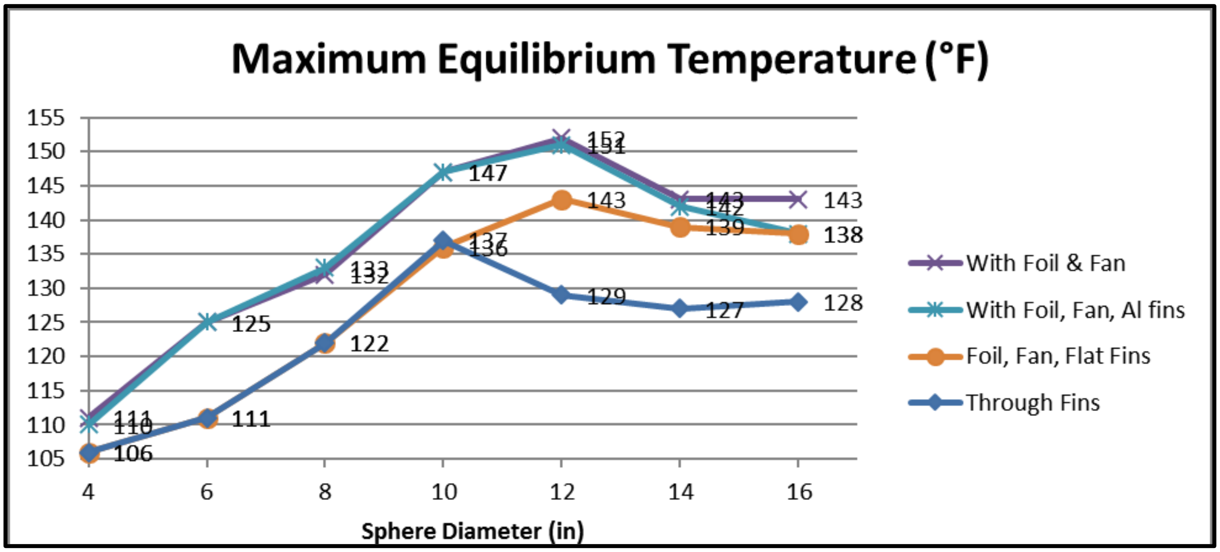

FIG 3: Maximum Equilibrium Temperature of seven sizes of heat sources, from four-inch to sixteen-inch diameter.

C. Simulations and Results

We conducted simulations on each design iteration. We started all gasses and solids at 310 K (100°F) and fifty percent humidity, as this is a reasonable worst case scenario the device might encounter. Some results of our simulations are shown. FIG 3 shows the equilibrim temperatures of four design iterations. The X axis shows the sizes of the heat sources; the Y shows the simulated equilibrium temperature inside the heat source. The curve displays interesting behavior. To the left of the ten-inch source, it shows a cubic rise similar to the rise in heat power in FIG 1. However, after that point, the equilibrium temperature falls. We have two explanations for this behavior: First, due to the power capping, the larger heat sources have lower heat power per unit surface area. Second, the larger heat sources rise higher in the container, and can take advantage of the heat sinks that encircle the upper region.

The equilibrium temperatures for some of the heat sources are higher than our goal of 120°F, but the results are nonetheless encouraging. First, it must be noted that the temperature curves in the above graph represent a temperature differential with respect to the exterior air. If the device is used in an 80°F environment, for example, the curves should drop by twenty degrees. Second, we expect that in real world testing, we will be able to make modifications that further increase thermal transfer, including using a larger fan or changing the configuration of the aluminum foil packed around the source.

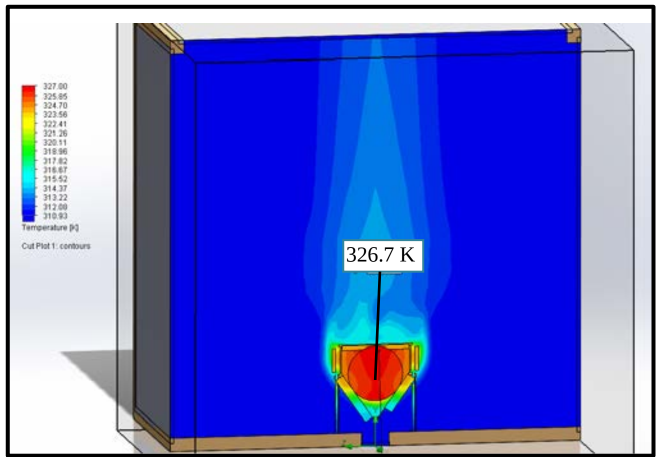

FIG 4: Heat contour map of sixteen-inch heat source simulation.

D. Next Steps

This project has been presented to a program manager in Nuclear Incident Response, and we hope to be funded to build a prototype. We are generating engineering drawings and working with our manufacturing partners to plan construction of the prototype. Once the prototype is constructed, we will perform real-world testing to further optimize the system.

II. SOIL DRYING UNIT

A. Project Description

Los Alamos National Laboratory supports efforts to prepare for nuclear incident response. Some functions of this mission include preparation for post-blast analysis, and to this end certain groups at the Laboratory train for field sample collection. The purposes of these operations are collection of post-detonation soil samples; processing of samples to facilitate sample testing; and identifying the "best samples with respect to the total number of fissions."[3] Previous exercises have shown flaws in the current sample processing methods. The on-site operators often encounter environmental factors that degrade the quality and usefulness of the samples. Wet, frozen, or snowy samples pose challenges to the chemists at Los Alamos, who are responsible for the post-collection testing. Thus, the sample drying project began.

As a member of a student team, I joined this project when it had been approved and funded, and the project assignment included several goals. We were to develop a machine that could dry half of a liter of soil in a short amount of time, preferably under half an hour. The finished sample should be light, powdery soil, rather than caked or packed soil. The system should be simple, light, and small, fitting within an eighteen-inch Pelican case for easy transportation. Finally, the system should if possible use commercial off-the-shelf (COTS) components, to facilitate maintenance and repair processes.

B. Design Process

Although the goals of the project were clear, the methods used to accomplish these goals were not established. Our team was tasked with choosing which systems to use. Before we began searching for a drying method, our brainstorming led to an added process—a press to squeeze the dirt prior to the drying process, to quickly remove as much water as possible.

The initial design concept had included a soil tumbler dry the soil, but our early research showed that commercially available tumblers are larger and heavier than desired. None of the units we found could fit in the Pelican case, and rather than build a small tumbler ourselves, we searched for alternatives.

We generated several ideas to accomplish the drying process. The first idea uses an enclosed kitchen mixer to rotate the soil while a 1200 Watt heat blower forces hot air through the chamber. This process should ensure that the sample remains loose and crumbly while being dried, thus fulfilling one of the project requirements. In addition, we posited that monitoring this system would be simple and informative: By measuring the humidity of the inlet and outlet air streams and comparing the two in real time, we could make an automated judgement regarding the moisture remaining in the soil. However, this system contains many moving parts, and we were concerned about the longevity of the components and the maintenance costs.

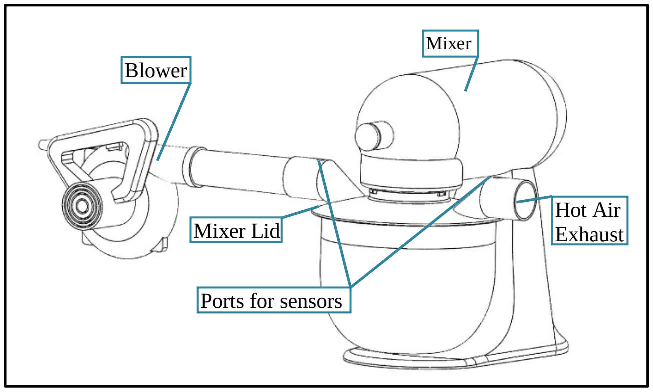

FIG 5: Layout of mixer system.

Our second concept involved a halogen oven. This common household item uses a high wattage halogen bulb and an interior convection fan to rapidly bake small quantities of food. The power of the model we chose was 1430 Watts, slightly higher than the wattage of the blower in the previous method, so we assumed that this method could result in faster drying times. However, the halogen oven is almost certain to result in a caked, hard sample when it is finished drying. To solve this derived problem, we knew we would have to develop a process to crush or pulverize the sample after drying.

FIG 6: Example of a halogen oven.

C. Testing and Results

After generating the design ideas, we tested them to discern which best fulfilled the requirements of the project. We purchased components, mocked up both systems, and conducted test runs.

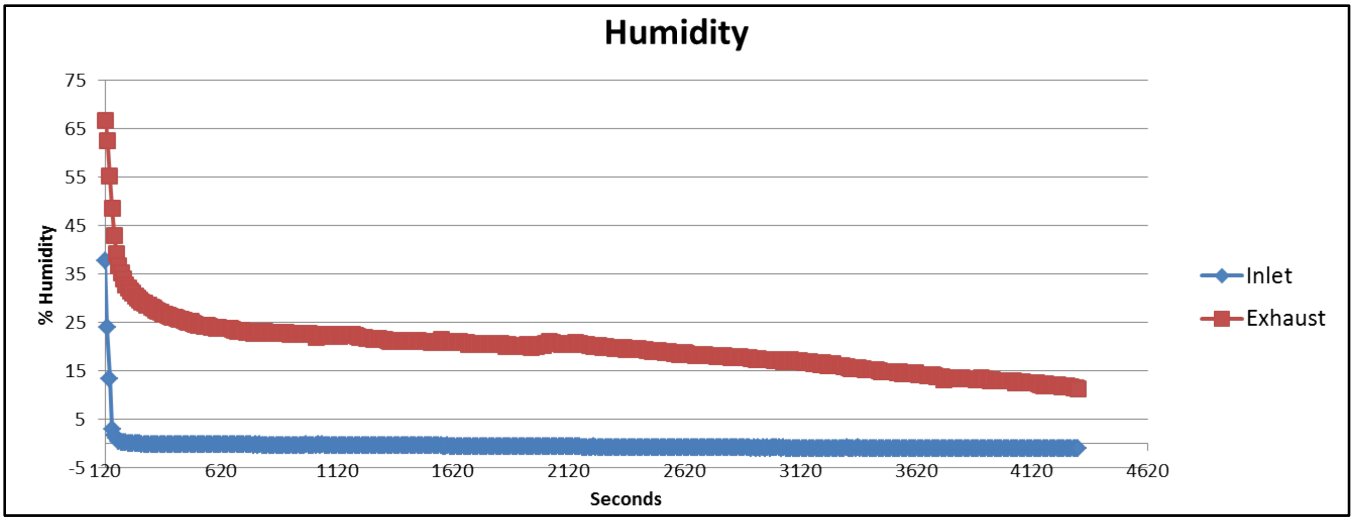

FIG 7: Example of air humidity data collection.

The composition of soil determines its ability to retain water. Sandy soils have a relatively large grain size, and therefore a lower total particle surface area per unit volume. On the other hand, soils containing clay have a much smaller particle size, increasing the total surface area and providing more bonding sites for water.[7] We expected that the higher water content in wet clay would result in longer drying times. To account for this, we conducted tests with the two types of soil from opposite ends of the spectrum: sandy soil and high clay soil.

The test runs demonstrated the strengths and weaknesses of the systems. The mixer was limited to 275°F, due to its plastic parts. However, it dried the sand sample in thirty five minutes. The clay on the other hand proved more difficult for the mixer to process, because it clumped up and clung to the sides of the mixer and to the blades. We designed clip-on blade adapters so that the mixer could more effectively reach all of the soil in the bowl, scraping it from the sides to prevent clumping. On our best run the mixer dried the clay in forty minutes. The humidity monitoring system yielded interesting results, and we are explored an Arduino algorithm to automatically notify the operator when the soil was dry. See FIG 7.

Testing the halogen oven showed that it quickly and effectively dries the samples. With the unit set to 430°F, the clay sample was dry after thirty minutes of operation, but the sand took thirty-five minutes, although it contained less water. One explanation for this behavior is that at these temperatures, the silica's hydrogen bonding to the water molecules is stronger than that of the high feldspar clay. As a result, the sand sample required a higher temperature before water vaporization. [8] As predicted, the resulting dry samples were hard and caked onto the drying pan, so we began to explore methods to crush the sample into the fine powder the project required.

D. Next Steps

Final testing on the systems will be completed in the coming weeks. When the testing is done, the team will evaluate the results in light of the project goals, and decide which drying system to use. Next, engineering drawings will be generated, and the best method for storying the system in the Pelican case will be determined.

III. CONCLUSION

As an undergraduate intern with an engineering applications group at Los Alamos National Laboratory, I had the opportunity to contribute to two major projects. These projects saw progress from the concept phase toward design, prototyping, and testing. The thermal source transfer unit began as a vague concept, and progressed to a novel design, effective in simulation and ready for prototyping. Our student team helped move the soil drying system from the design phase into testing.

In addition, while working with A-3 I had the chance to develop professional skills that will assist me as I begin my career. I began to understand how an applications engineering group works together, from the engineers to the drafters to the machinists. I learned hard skills such as computer simulation, software coding, mechanical design, testing, and analysis.

Finally, the research and development I engaged in helped me learn which areas of my field I enjoy working in. I realized that I enjoy research projects, and I look forward to shaping my future career based on this direction. As I transfer into a university I will look for opportunities to join other engineering research projects, so I can make use of what I have learned at Los Alamos National Laboratory.

IV. ACKNOWLEDGEMENTS

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