Insulation Testing

Final Report

SOLAR COOKER PROJECT

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Authored by: Trang Pham and Jae Hong Lee

1. Summary

In order to improve performance of solar oven, previous insulation testing team constructed an experimental testing unit to learn more about the properties of difference insulation materials. Unfortunately, while testing to determine the degradation of insulating capacity of woodchips (wood shavings), the wood components of the test enclosure were subjected to pyrolysis (conversion of the wood to charcoal) through extended and cyclic exposure to high temperature [(1)]. Because of this incident, the previous insulation team constructed a new testing unit, replacing the inner wooden case that was directly exposed to the heat-source with a steel case. The new testing unit needed to be tested for consistency with the old test unit before further studies can be done. The insulation testing team identified two objectives for this semester. The first objective was to modify the *experimental wall* [(2)] component of the new test unit. The second objective was to test different insulation materials using the new test unit, to compare the results with the old data collected in previous years using the old testing unit.

First, the insulation team identified the characteristics desired for the *experimental wall*. The team decided that the experimental wall should somewhat mimic the current solar oven's door and should be stiff enough to hold the shape of the insulation materials being tested. A trapezoidal shaped box was constructed using wood and fiberboard, and wrapped with aluminum sheet.

Second, the team tested the same insulation materials used by previous insulation testing team: air, fiberglass batting, wood chips and rice hulls. The test results were fairly consistent and the team concluded that the new test unit could be used for further experiments with different insulation materials.

It should be noted, we are still not quite sure whether the new test unit could perform extended exposure to high temperature cycles or not. (Why? Because of my fear of running the tests unattended?)

2. Introduction

Insulation plays an important role in retaining heat generated by converting the solar energy that is absorbed and converted to heat by the black plate inside the oven. Broadly, there are two major issues of concern: performance and durability; both issues are significantly impacted by the properties of insulation material and the design of insulation inside and outside the oven.

This semester's insulation testing team had two main objectives. The first objective was to modify the experimental wall to increase its durability, reducing the risk of pyrolysis and ignition. The second objective was to assess the new test-unit and compare its performance with the old test-unit.

[(1)] For more information, refer to Spring 2011 - Insulation Testing Final Report – Section 3.3

(2) Refer to section 3.1 for further description.

3. Experimental Wall Modification

3.1 Problem

Previous insulation testing team constructed the experimental wall using plywood. This induces the risk of ignition. Also the plywood used was thin and flimsy which created a concern for maintaining and controlling the form and volume of insulation materials. The bottom area of this experimental wall was slightly bigger than the inner case opening, allowing the experimental wall to rest on the inner case. In addition, the old method to seal the experimental wall was to place weights on top of the cover of the experimental wall; the additional weights might potentially deform the flimsy wall, creating different testing conditions for each trial and causing unexpected errors.

3.2 The New Design

The new design of the experimental wall was inspired by the current solar oven's door design. Instead of a rectangular box shape, the team went with a trapezoidal shape, tapering the sides of the wall to easily fit into and seal with the inner case. The materials for bottom and sides of the experimental wall were changed to fiberboard, which is stiffer and more durable than plywood, providing stability for the wall. Furthermore, the experimental wall was wrapped with aluminum sheets on the bottom and sides to prevent direct exposure of heat to the fiberboard. The new experimental wall is sealed by a wooden lid which can be secured using four threaded bolts and wing nuts. The lid acts both as a seal and frame to hold up the experimental wall which was required by the new shape. This system allows for the insulation materials inside the experimental wall to be easily interchangeable. The new experimental wall has the following dimension:

Bottom width: 6 ¾ in. Top width: 7 in. Volume: 378 in^3

Height: 2 ½ in. Length: 22 in.

Figure (1) Test Unit – Experimental Wall – Lid

4. Insulation Testing Methods

4.1 Overview

4.1.1 Test Unit Breakdown

The insulation test unit was constructed using a heated box mechanism. The unit consists of an outer case made of plywood, thick layers of fiberglass on the bottom and four vertical walls, an inner case made of steel sheet, a heat source comprised of four 500 watt halogen lamps which sits inside the steel case, and an experimental wall to seal the unit and hold the insulation being tested. The thick layers of fiberglass were installed between the outer and inner cases of the unit in order to force majority of heat flow from the heat source to dissipate through the upper wall of the box, called the experimental wall. The experimental wall was designed for easy installation and removal of insulation materials

4.1.2 Set-up

First, the heat source was constructed using four 500-watts halogen light bulbs. Power to these light bulbs is controlled by an automatic system that implemented as a LabVIEW program. This program uses seven thermocouples to measure the temperatures inside the test unit and regulate the flow of electricity to the light bulbs in order to turn them on and off. Seven thermocouples were installed at different locations inside the test unit as demonstrated in Figure (2). The program uses these devices to measure and record the temperatures at these locations every second.

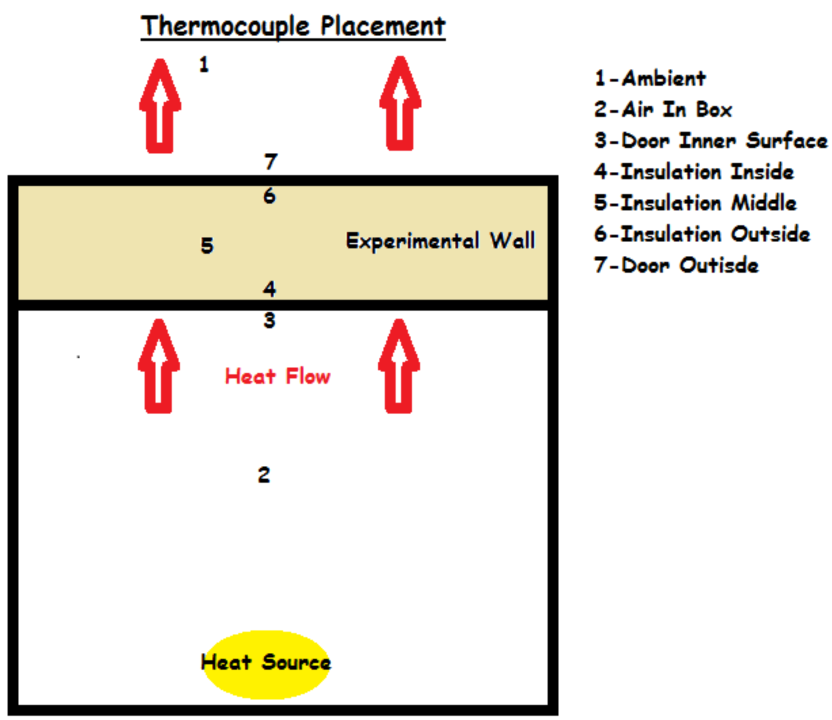

Figure (2) Diagram of Thermocouple Placement (courtesy of Insulation Testing team – spring 2011)

4.2 Procedure

LabVIEW controlled the heat source based on four input parameters:

- Target hot temperature

- Hot hold time
- Target cold temperature
- Cold hold time

Target hot and cold temperatures indicate the temperature differences between the temperature in the box and ambient temperature. Hot hold time and cold hold time inputs indicate the time durations desired to maintain those target temperatures by turning on and off the heat source.

4.3 Testing and Data Collection

To be consistent with previous insulation team's testing methods, target hot temperature was set at 150^oC (difference between ambient and the temperature inside the heated system), hot hold was set to 1000 sec, target cold temperature was set to 10^oC, and cold hold was set to 30 sec. Since the cooling process was not our primary concern for this specific study, the data collection was cut off after hot hold phase ended.

Our first insulation material for testing is air as it is a natural insulator and a reasonable material to compare to as a control. With air, we were not sure how long the hot hold period should be, therefore, the amount of data was less than other insulation materials. After consultation with a member of previous team, and our own observation, the team decided that a hot hold period should last for 1000 sec. This time range was long enough to allow heat to dissipate slowly through the insulation layer inside the experimental wall so that significant difference between different insulation materials could be clearly observed.

Next, the insulation team tested fiberglass batting. Six trials were conducted for this material. Since fiberglass maintains its shape quite well, no special method of placement was required. Our team was curious about what would happen if we prolonged the hot hold phase. A trial test was done by setting the hot hold input to about 23000 sec (approximately 6.4 hours).

Lastly, the insulation team tested woodchip and rice hulls, two alternative insulation materials that are locally available in Nicaragua. Since woodchip and rice hulls' bodies are not really rigid and cannot maintain their shapes, extra measures need to be taken into consideration, specifically the mass/volume ratio of insulation material.

The experimental wall was weighed by itself, using two table electronic scales, one on each end of the wall. Then it was again weighed with either woodchip or rice hulls filled-up inside the wall. The difference in weights indicates the actual weight of the insulation material inside the experimental wall. For our experiments:

Mass/Volume ratio of wood is: 409.9g / 378.125in^3 = 1.08 g/in^3

Mass/Volume ratio of rice hulls: 677.3g / 378.125in^3 = 1.79 g/in^3

4.4 Data Analysis and Results

After all data was collected as desired, LabVIEW produced a spreadsheet which consists of temperatures recorded at all eight locations at every second. Among them, temperatures at four locations were focused on: Ambient, Air in Box, Insulation Inside and Insulation Outside. The temperature difference from bellow the insulation layer to the top of the insulation layer was calculated: ΔT

$$\Delta T = T_{Insul.Inside} - T_{insul.Outside}$$

After calculating ΔT, a scatter plot was created, starting at $\Delta T = 10^{o}$C, in order to be consistent with previous team's method.

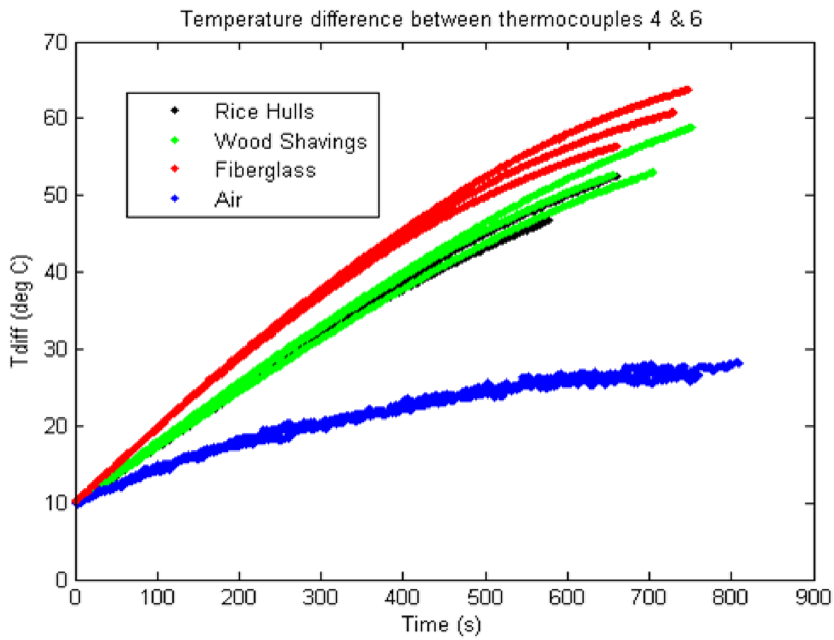

Figure (3) Old test unit results

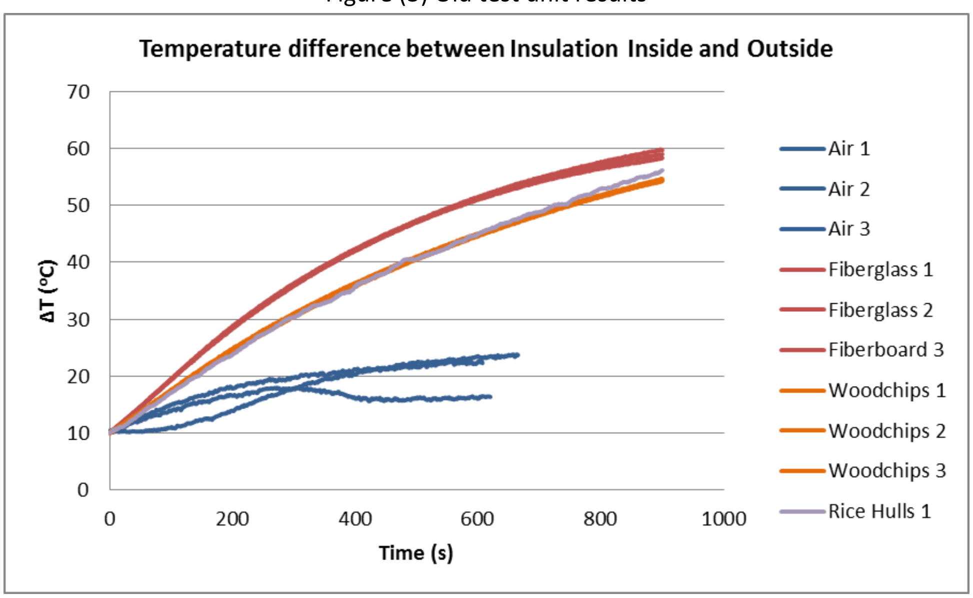

Figure (4) New test unit results

The results for fiberglass, woodchips and rice hulls were consistently higher than the results from previous team. The new ΔT seems to be 9^{o}C to 15^{o}C higher than the old ΔT. This could be explained by the introduction of fiberboard to the experimental wall.

Fiberboard acts as insulation layer itself, adding to the ability of the experimental wall to insulate heat. The wide range of difference (9°C to 15°C) was probably because the mass to volume ratio of woodchip and rice hulls were not optimized; the ratio used did not allow for the best performance from woodchips and rice hulls. (Is a greater temperature difference good or bad? How do you explain the delta T?)

As for air, the results significantly varied and did not show any strong pattern. Our team agreed that these variations could be due to the fact that air circulates rather fast within the 2.5in depth of the experimental wall, making it more of a heat transfer medium than an insulator.

In addition, when the insulation team observed the data more closely, we found that ΔT reached the difference of 10°C at different $T_{air\ in\ box}$ in different trials. The team was curious about what effect does the $T_{air\ in\ box}$ have on the insulation process. We decided to hold the condition of the starting points on the graph constant by plotting ΔT starting when the Hot Hold phase began. This will assure the temperature inside the test unit to be the same for every trial. As shown in Figure (5) below, the rate of insulation is relatively the same for each trial as the curves are relatively parallel. However, these curves were either shift up or down. One possible explanation would be that there were variations in initial conditions of each trial; some trials were started at ambient temperature while others were not. Yet, the result for test 1 showed quite significant difference from other trials. This could have been due to the shifting and changing shape of the fiberglass layer while conducting this test.

We also tried analyzing the trials, searching for trends that could indicate insulation material's durabilty; however, there was not any strong indication of a particular pattern relating to material's durability. More tests would be needed in order to further analyze in this direction.

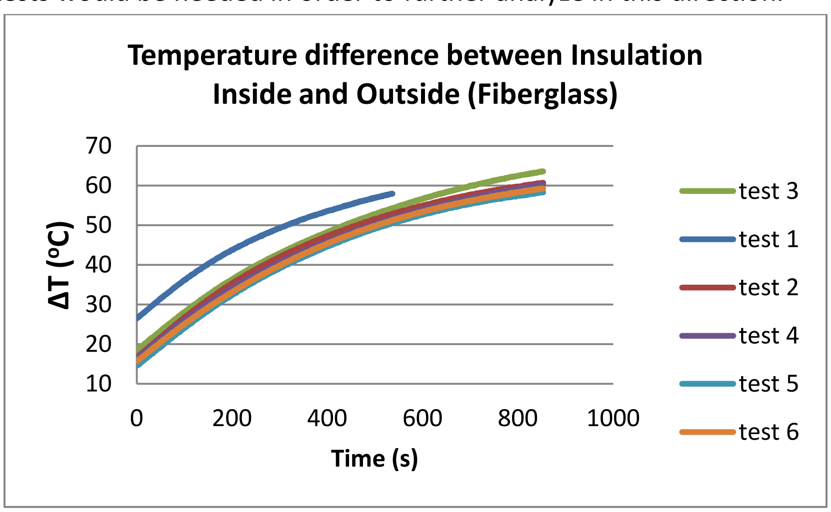

Figure (5) Plot when $T_{air\ in\ box}$ reached 170°C

Our insulation team was curious as to what happens when the Hot Hold phase was prolonged for an extended period of time. As observed in previous trials, ΔT kept on increasing but with a decreasing rate, therefore, we expected ΔT to converge(with what?).

We conducted an experiment to study this characteristic of fiberglass by setting the Hot Hold input to about 23000 seconds.

As showed in Figure (6), ΔT started to level off at approximately 7500 seconds. After approximately 10000 seconds, ΔT fluctuated very gently around 99.9^{o}C with a variation of 0.03^{o}C on average. The result suggests that the relative insulating capacity of fiberglass is about 100^{o}C in the testing unit when the input hot temperature of approximately 150^{o}C is maintained. This capacity is considered relative because the value is subject to change depending on designs of the testing unit and the thickness of fiberglass layer. However, for the purpose of choosing the material with the best insulation characteristics, this test clearly identifies the material with the best insulating capacity.

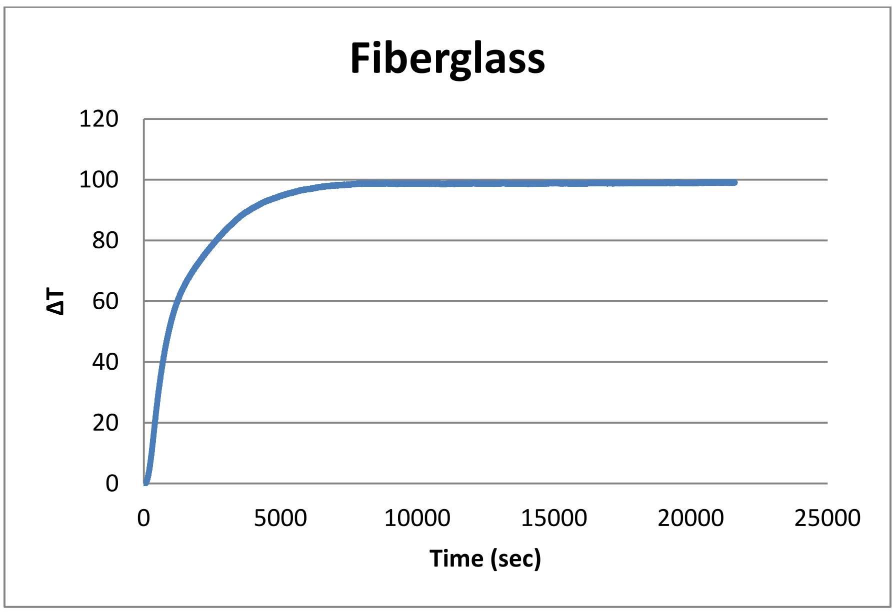

Figure (6) Fiberglass converged to ΔT of 100^{o}C

5. Conclusion

With the results found above, the insulation team came up with the following conclusion:

- The new test unit showed results consistent with the old unit and, therefore, it is ready to perform further insulation tests.
- Since woodchips and rice hulls cannot maintain rigid shape and volume well, the optimal mass to volume ratio need to be determined.
- Initial condition of test trial should be decided and maintain for all trials in order to improve consistency between trials data.

6. Recommendation for Future Work

- Determine the optimal mass to volume ratio of non-rigid materials like woodchips and rice hulls.
- Study the degradation of the insulating quality of different insulation materials to compare their durability.

- Determine the ΔT convergence of woodchips and rice hulls after an extended period of time.
- Test other insulation materials.