Concentrated Cooker Final Semester Report

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Introduction

Our primary focus this semester was to develop a way to direct more light into the solar ovens, thus increasing their overall efficiency. Last year the concentrated cooker team used a precise petal construction method to develop a parabolic reflector; however, they ran into difficulties in choosing the material. Material that was sturdy enough to hold its own was too unyielding to the point-to-point construction system, and due to these unresolved difficulties, we brainstormed an entirely new approach. Instead of working with parabolic mirrors, we chose to focus on Fresnel lenses (See Literature Review).

Our original objective was to optimize the capability and efficiency of the existing solar ovens by harnessing more sunlight than they do currently, using the lenses to access and redirect more light. However, as we learned more about the lenses, our objective evolved to better match their function and limitations. This paper details the progress of our work over the semester and outlines our future goals for the coming semester.

Literature Review

The Fresnel lens was invented in 1822 by French physicist Augustin Fresnel with the intention of creating a lens that would use less material than the conventional lens. Its first commercial use involved making dispersed light emanating from a torch into a co-linear beam in a lighthouse (Fresnel 2011). The lens functions by preserving the outer curvature of the conventional lens—where the refractive power is contained—while removing most of the internal material (See Figure 01). Image quality is sacrificed, but otherwise the lens functions as a conventional lens (Davis & Kuhnlenz).

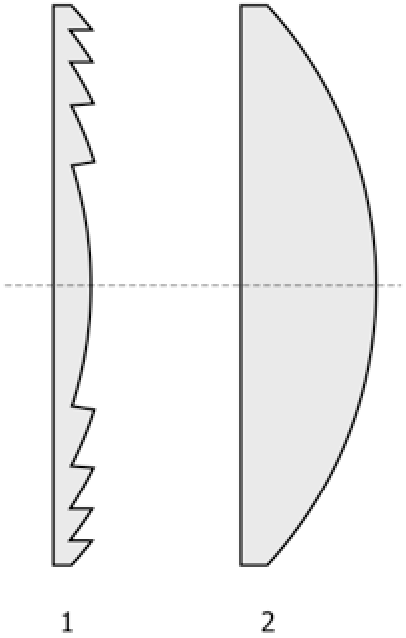

Figure 01: Fresnel Lens versus Conventional Lens

Davis and Kuhnlenz of Reflexite Optical Solutions describe Fresnel lenses as a "cost-effective, lightweight alternative to conventional continuous optics" (David & Kuhnlenz). As opposed to conventional lenses, which can be bulky and fragile, Fresnel lenses are characterized by their flexibility and thinness, making them advantageous for our initial testing.

Because Fresnel lenses can converge light from a large area to a smaller one, one of their most basic applications is in solar concentration. Positioning the lens at the correct angle to the sun will maximize solar radiation onto the chosen focal point (David & Kuhnlenz). Although we have described Fresnel lenses as non-imaging lenses, the concentration of solar radiation requires no consideration for this feature and makes the trade-off of image quality for material conservation irrelevant to our purposes.
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Test Procedures This Semester

In our first set of trials, we looked for ways to mimic the sun's rays of parallel light to test the properties of the lenses. Unfortunately, the lights in the laboratory, which are typically used for testing the solar ovens, do not emanate beams of parallel light; the light from the bulbs is too dispersed to yield useful results with our lenses. Therefore, we used laser pointers as a source of parallel light. From testing the lenses with lasers, we were able to confirm the functionality of the lenses and determine their focal length, which was about 33 cm (See Figure 02). Mapping the lenses with lasers was our first experiment with their properties.

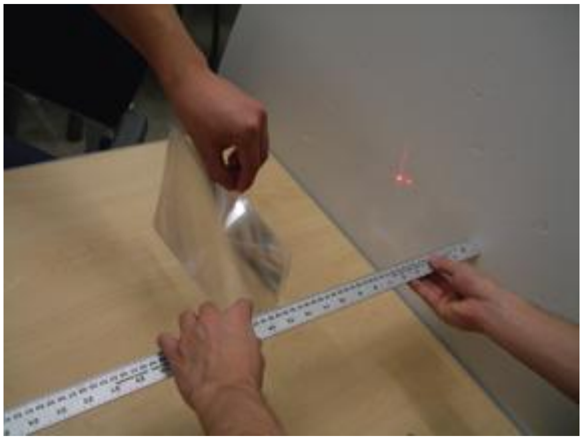

Figure 02: Focal length

Figure 03: Single Focus Set Up

Our second set of trials was a simple test in which we tested the lenses outside on a cold day, mounting the lenses with a clamp stand (See Figure 03). Positioning them so that they were optimally angled towards the sun, we focused them at a point on the ground and measured the temperature with a thermocouple attached to a washer at that point. To ensure that we were getting the data we needed, we had previously painted the washer black to maximize the conversion of light into heat. The lens focused light to an area about the size of a nickel, and the thermocouple reported temperatures upwards of 270°C on a day when the ambient temperature was about 17°C in a manner of minutes. From testing the lenses in sunlight, we were able to see how they work and how they function in their most basic set up.

After realizing that these high temperatures could be reached in such a short amount of time, we wanted to gain more insight into how the lenses could be used to heat, and potentially, boil water. If we could get the water to reach 100°C, it would have very positive implications for the use of Fresnel lenses. Our first test that attempted to heat water involved using a full sized pot (one of the ones typically used for cooking in the solar oven), but with only 250 mL of water in it (See Figure 04). Despite our attempts, the results indicated that the water temperature changed by a negligible amount compared to the ambient temperature. The size of the lenses compared to the size of the pot is such that the lenses don't bring any light to the pot that would not be reaching it already. This forced us to revise our tests to account for this discrepancy.

Figure 04: Full-sized pot attempt

Figure 05: Scaled-down pot modification

The revision of the water heating test was to use scaled down pots to hold the water (See Figure 05). The pots we used were about 24.5 in^3, and we anticipated that the lenses would concentrate light onto them that would not reach them otherwise. Although this test saw more success than the initial test (see Figure 06), the difference in temperature between the pot with and without a lens directed at it was not significant enough to indicate success. Contributing to this result was the cold ambient temperature and substantial wind, which drew heat away from both un-insulated pots significantly.

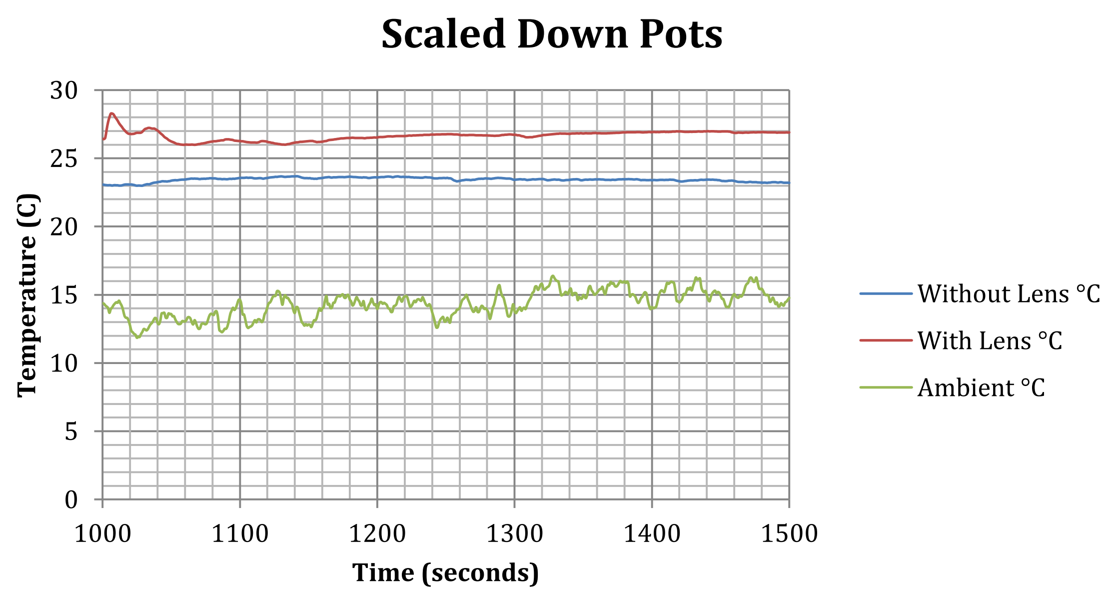

Figure 06: Small Pot Temperature Comparison

Our next set of trials involved comparing what would happen when the temperature was measured before and after the focal point, versus when the lens was out of focus. ?? Does this mean measuring in front of and behind the focal point of the lens?? This comparison would provide useful information about the limitations of the lenses, as we already knew how they worked when they were positioned optimally. From performing these tests, we gained insight about the trade-off between the area of light concentrated to and the amount of energy concentrated (See Figure 07). More importantly, we learned that if the lenses are not focused perfectly they actually become impediments to the process, blocking light. In this case, they did not heat the washers to high temperatures. One problem that this test made us aware of was the difficulty in determining whether the lenses are angled properly when we cannot see light concentrated to the focal point. It is only at the optimal focal length that it is obvious that the lens is in focus.

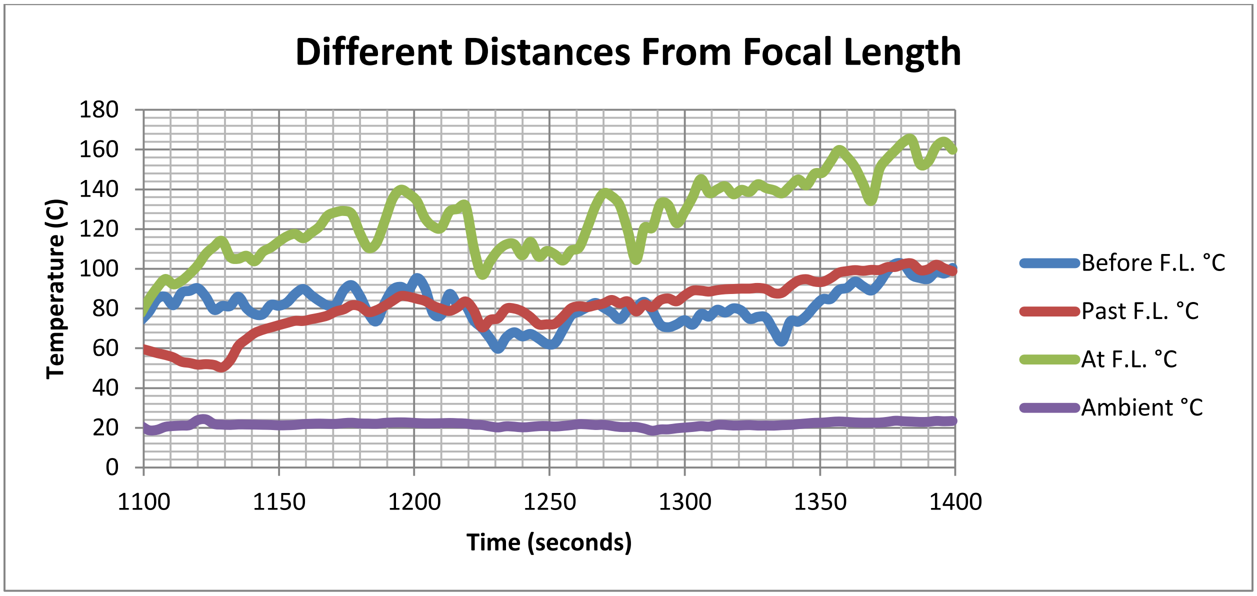

Figure 07: Distance From Focal Length Comparison

Another test that we performed was the attempt to fry an egg in a black pan using a single Fresnel lens (See Figure 08). While we were totally unsuccessful at this task, the results of this test exemplified what we had learned so far. At the focal point, the egg cooked entirely, which was impressive for a day where temperatures were around 15°C, while everywhere else the egg was actually probably slightly less cooked than it would have been if the lens had not been present because the lens blocked light from the rest of it (the lens actually redirected light to the focal point that would have reached other parts of the egg, it didn't block light). This round of tests showed us that the critical feature of making gains using the Fresnel lenses was that the lenses had to concentrate light to the object being heated that would not reach it already. This could be achieved by using a much larger lens, which would concentrate large amount of light to the focus that would not typically reach it, or by creating a design that would redirect light onto the specimen. Because we did not have access to a larger lens, this led to the final test set up of the semester, which used a mirror to redirect light.

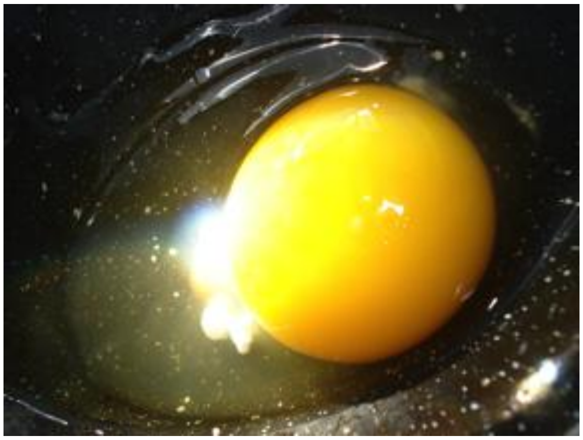

Figure 08: Attempt to fry an egg

The final set up that we tested used two lenses and a mirror. The first lens directly intercepted sunlight and concentrated it to a single focal point. Meanwhile, the mirror reflected light from behind the focal point into another Fresnel lens, which concentrated it to the same focal point as the original lens (See Figures 09 and 10). The results of this test (see Figure 11) indicate the direction we want to pursue next semester.

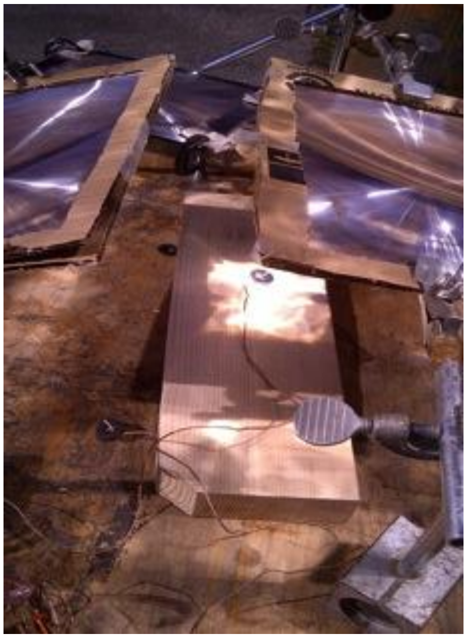

Figure 09: Dual lens set up

Figure 10: Mirror reflecting light

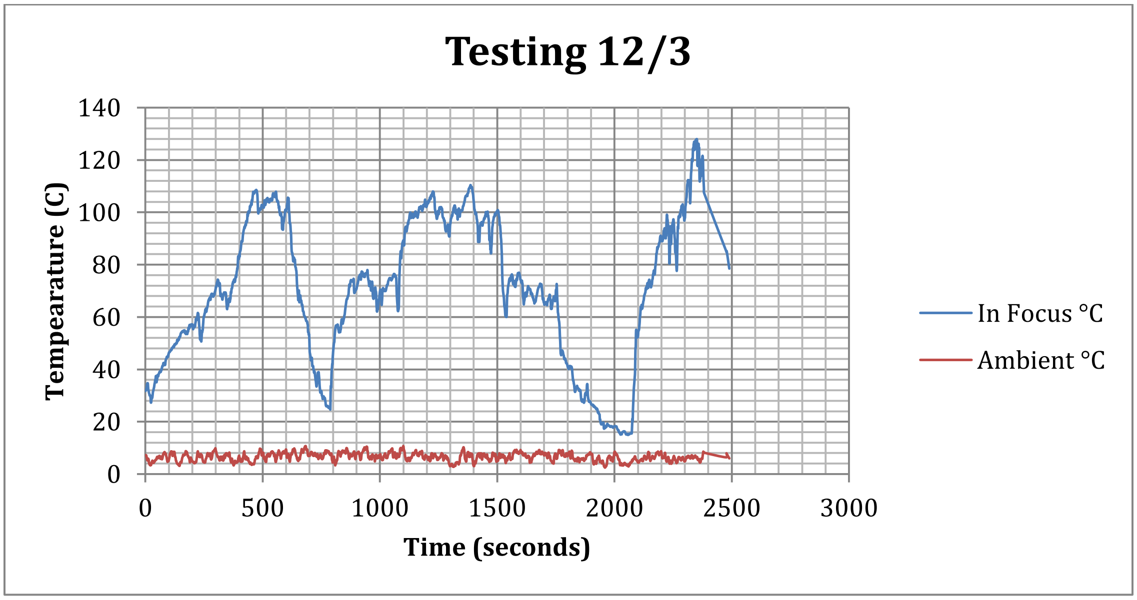

Figure 11: Results. The final peak, which shows the highest temperature, is the set up which used two lenses.

Problems Encountered/ Sources of Error

Of the problems that we encountered this semester, the main ones that hindered our ability to test the lenses were:

- Weather conditions were not ideal for as frequent testing as we would have liked. Limited sunlight dictated the days we were able to test, and even on days that were sunny, slight winds could take away the heat accumulated.
- Sun conditions varied day-by-day and moment-to-moment. This made our results harder to interpret, especially because we compared the recorded temperatures read by the thermocouples, not recorded light intensity.
- Constant movement of sun meant that for optimal performance we would need constant adjustment of lenses--or else the lens actually blocked some light. With our haphazard set up, this potentially created some inconsistencies.
- Safety hazards, such as the risk of lighting things on fire or eye damage, required caution.
- The small lenses, while useful, do not provide as much insight into their capabilities and limitations as a large lens would have in some circumstances.

These limitations created the potential for some inconsistencies of which we are now aware, and we can now focus on eliminating them during the early stage of next semester.

Future Goals

Our most recent experiment, which utilized the mirror and dual-lens set-up, was a success and opened up many possibilities for future work. With the method, we successfully redirected more sunlight into our target area and enhanced the heat-up rate dramatically. In the future we will try different combinations of mirrors and lenses to optimize our design and further investigate this idea.

Something that limited our experimentation greatly was the size of our lenses. Although we did our best to keep everything in proportion, it became apparent that the fact that the size of the lens is directly proportional to the amount of energy it can use. To get the kind of results applicable to the solar cookers, we will need to purchase a larger lens, and we will be looking into this next semester.

Experimentation also revealed that the lenses only work to their maximum efficiency at a specific angle to the sun, which technically would be constantly changing as the sun moves throughout the day. Ideally, then, the lenses should be able to move along with the sun, and to this end we have been toying with the idea of a kind of mechanism that would move in an arc with the sun, keeping the focal point in the center at all time. This design will require much more thought, and as of now it is a very preliminary idea. Either way, we want to look into designing and constructing a better frame for the lenses, whether or not we decide to make the circular motion aspect a reality. Therefore, one of our future goals is to create a frame, but we will need to decide what direction we want to take with it before investing too much time in its construction and finalizing our design idea.

Finally, we were inspired to look into ways Fresnel lenses could be used outside of the design for solar ovens. Solar panels, for instance, are often fairly inefficient, as very little of the sunlight that hits them is converted to electricity. The way we have been approaching Fresnel lenses for our purposes might also be applicable to enhancing the performance of these solar cells, and if we have time next semester we are interested in exploring this.

Conclusion

Our initial objective focused entirely on enhancing the original design that we were presented with, adapting what we learned about the lenses to the existing solar ovens. However, after our experimentation, we realized it might be more effective to go in another direction entirely. Instead of thinking in terms of the solar cookers, we can now think of ways in which to devise the best system of using the lenses as possible, and then make adaptations later.

We also want to communicate with Grupo Fenix and Las Mujeres Solares de Totogalpa in Nicaragua about potential needs that could be met with Fresnel lenses and the research that we have accumulated thus far.

I think you should measure the intensity of the incident solar radiation, which can be done with a pyranometer, to allow you to quantify the energy available and the efficiency of the capture or conversion of energy. The pyranometer will give you the actual light intensity available during your tests. You don’t mention developing or using methods to reduce heat loss, by protecting against wind, either by shielding the test set up or providing a transparent containment around the target to be heated. We can get larger lenses and work on or with better frames for holding and positioning the lenses.

References

Davis, Arthur, and Frank Kuhnlenz. *Optical Design using Fresnel Lenses: Basic principles and some practical examples*. *Reflexite*. Reflexite Optical Solutions Business, n.d. Web. 10 Dec. 2011. <http://www.reflexite.com/tl_files/EnergyUSA/papers/Optical-Design-Using-Fresnel-Lenses.pdf>.

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