ARTI Charcoal Solar Briquette Dryer Improvement Project Report

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Introduction

In sub-saharan Africa, 4 out of 5 households depend on charcoal and wood for cooking and heating in their homes[1]. Most of the charcoal is created from wood, which can contribute heavily to deforestation. At the same time, many agricultural waste products have combustible properties that are not taken advantage of. The D-Lab Scale-Ups program has partnered with the Harvest Fuel Initiative and ARTI-Africa to produce charcoal briquettes from these organic waste products[2]. These charcoal briquettes can be used in place of traditional wood-based charcoal, to help alleviate the problem of large-scale deforestation that the use of traditional wood charcoal briquettes creates.

ARTI-Africa's charcoal briquette production plant near Dar es Salaam, Tanzania recently changed locations to allow for a higher production rate. The new machinery can produce over 5 tons of charcoal briquettes per day – a five-fold increase over the old plant. However, drying the charcoal briquettes has become a bottle-neck in the production process. Sun-drying can take up to 10 days per briquette, and there is not enough space at the factory site to allow the full capacity of briquettes to be produced and dried. While previously briquettes were laid out in the sun to dry, a solar dryer prototype has been designed and built to help speed up the briquette drying process. However, initial tests of the dryer show little improvement over conventional sun-drying.

This past IAP, tests were run on the initial dryer to determine its drying capabilities. Improvements were made, and subsequent tests found increases in the dryer's ability. However, the final dryer's capability and capacity were still not as good as conventional outdoor drying, so it seems that the cabinet dryer is not the best solution to the drying problem for charcoal in Tanzania.

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Project Goals

- Determine drying capability of baseline system (outdoor racks)
- Understand drying ability of cabinet dryer
- Improve cabinet dryer/Implement SmartDryer System

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[1] GACC. Global Alliance for Clean Cookstoves: Data & Statistics. (2014). at <www.cleancookstoves.org/resources/data-and-statistics>

[2] Harvest Fuel Initiative. at <www.harvestfuel.org>

- Determine whether cabinet dryer should be scaled up

Project Summary

At MIT, we explored drying properties of charcoal briquettes, determining that high temperature helped drying more substantially than high air flow rate. We set out to test this theory in the field at the ARTI charcoal briquette production site in Dar es Salaam, TZ. The main purpose of this experiment was to evaluate the drying techniques available and to improve them if possible, with the added goal of further understanding how the briquette drying process works.

The preliminary drying method used by ARTI involves drying racks, which hold multiple trays of briquettes which are left out to dry in the sun. During the night or when it is raining, tarps are placed over the racks to protect briquettes from the moisture. Unfortunately, this prevents the wind from moving through the briquettes and causes excess humidity to gather. Furthermore, this method does not provide efficient drying when it is raining.

To fix this problem and to shorten the drying time, a solar powered cabinet dryer was built. The cabinet dryer consists of a heating chamber, where air heats up, as well as a cabinet, where briquettes are placed to dry. The cabinet has a fan in the ceiling to promote airflow through the cabinet. Initial tests on the cabinet showed that it did not increase drying time, so the first test we did this IAP was to confirm those results.

Also at MIT, the SmartDryer system was developed by Richard. The goal of the system was for the fan at the top of the cabinet to turn on only when humidity inside the cabinet was higher than a certain setpoint. This would ensure that the fan would be off for enough time for the temperature to rise, but would turn on once it became too humid inside of the cabinet. The system runs using a 12V battery, which can easily be charged with a solar panel.

Testing Methods

At MIT, we ran tests at the following conditions to determine the effects of temperature and air flow on briquette drying:

1. Low temperature without air
2. Low temperature with air
3. High temperature without air
4. High temperature with air

For each of these, four to eight briquettes were made, their masses measured, and then were placed in the drying oven. Their masses were recorded every two to four hours during the day, and time taken to dry was recorded.

During IAP, we tested the drying rate of briquettes in the following conditions:

1. Baseline: Outdoor Racks
2. Confirmation: Cabinet System

3. Improved Cabinet System (with SmartDryer)
4. Improved Cabinet System with Delayed Use
5. Charcoal Stoves under Outdoor Racks

For each condition, briquettes were extruded, placed on a tray, and then massed. The mass was then recorded at two hour intervals during the day over the course of the next three to eight days, depending on the test. For the first three tests, briquettes were placed in the drying system being tested directly after being massed. In the final (delayed use) test, briquettes were not put inside the cabinet until they had dried outside for two days, relieving them of their initial moisture. Numerical mass transfer coefficients were calculated by fitting a exponential curve to mass-time data, with larger mass transfer coefficients corresponding to faster drying. The following equations (Ekechukwu 1999) allowed us to calculate these coefficients.

$$\frac{dM}{dt} = -K(M_t - M_e)$$

$$\theta = (M_t - M_e)/(M_o - M_e) = e^{Kt}$$

In the above equations, M_o represents the initial mass percent moisture, M_e represents the percent moisture at equilibrium (when the briquette is considered “dry”), and M_t represents the mass percent moisture at the given timepoint.

Baseline Testing

In the baseline rack test, briquettes were placed on the outdoor drying racks and their masses were measured over the course of a week. We tested briquettes on the top, bottom, and middle of the racks separately to see if there was a difference in drying time based on position. In the baseline cabinet test, the briquettes were placed in the drying cabinet directly after extrusion and initial mass measurements. The cabinet was filled completely with briquettes, and the fan on the top was left off.

Dryer Improvments

The cabinet dryer improvements consist of three of the four wooden cabinet walls were replaced with translucent plastic, in the hopes that sunlight would move through the walls and hit the charcoal directly, thus heating the briquettes rather than the cabinet walls. Second, mirrors were added around the solar collector to direct more sunlight to the collector and increase the temperature of the air entering the cabinet. Finally, the SmartDryer system was installed, so that the humidity inside and outside the cabinet controlled whether the fan was turned on.

Improved Cabinet Dryer

Delayed Use

The purpose of the delayed use test was to determine whether the cabinet dryer would make a significant decrease in drying time if it was used during the latter part of drying rather than the initial phase. This idea sprang from a meeting with Dr. Rajabu at the University of Dar es Salaam, who suggested that the reason the cabinet dryer might not have been performing well was because in the initial drying phase moisture was leaving the briquettes at such a fast rate that the cabinet became too humid to function correctly. The goal was to allow a large amount of moisture to leave the briquettes first, then to move half of them into the cabinet and compare the drying rate between those left on the racks and those in the cabinet.

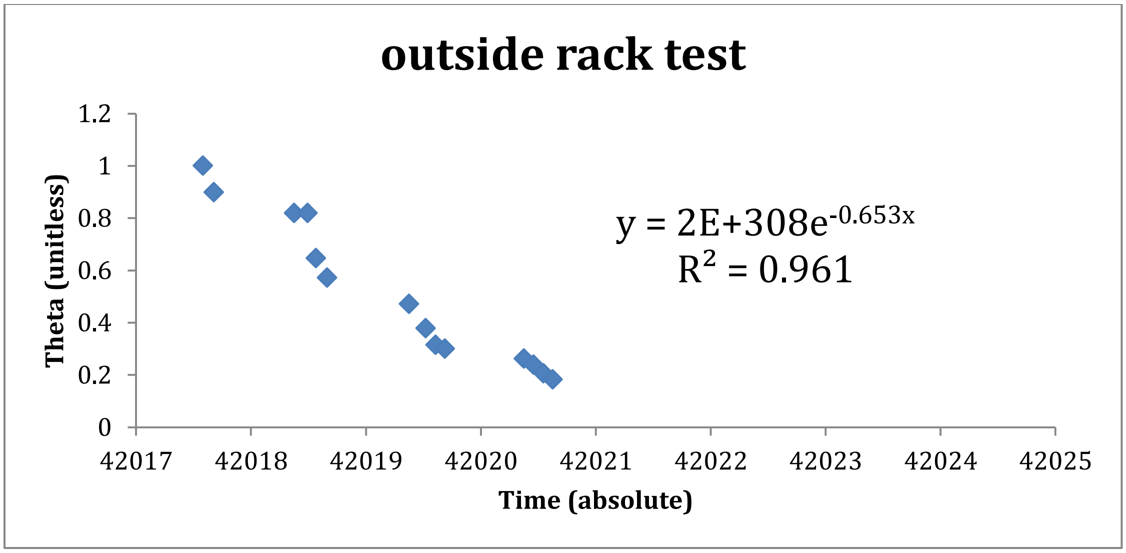
Overnight Stoves

The final test that was run over IAP was placing charcoal stoves under the drying racks overnight. The goal was for the heat from the stoves to speed overnight drying.

Results

For all tests, data was analyzed in the following manner. First, theta (from equation 1 above) was plotted on the y-axis, against time, which was plotted on the x-axis. An exponential curve was fit to the data, and the coefficient on x was reported as the mass transfer coefficient. A higher mass transfer coefficient corresponds to a faster drying rate.

An example graph plots theta on the y axis and time (in universal units) on the y axis:

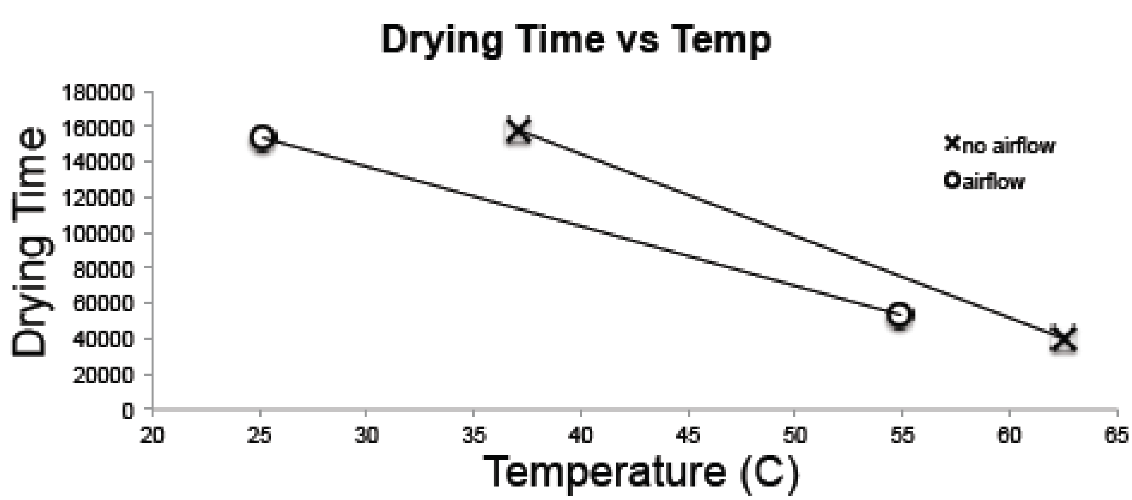


The exponential equation plotted to these data is shown on the graph, and we can see that the K value is 0.653. All data was analyzed in this manner.

MIT TESTING

For briquettes tested at MIT, rates measured were on the scale of 10^-5. Since drying occurred within about three days for most briquettes, it was also possible to measure the drying time required for each sample. Results for both tests are below.

Avg Temperature (C)	Air Flow	K Value (x10^5) (1/s)
37.1	no	1
62.5	no	4
54.9	yes	2
25.2	yes	1

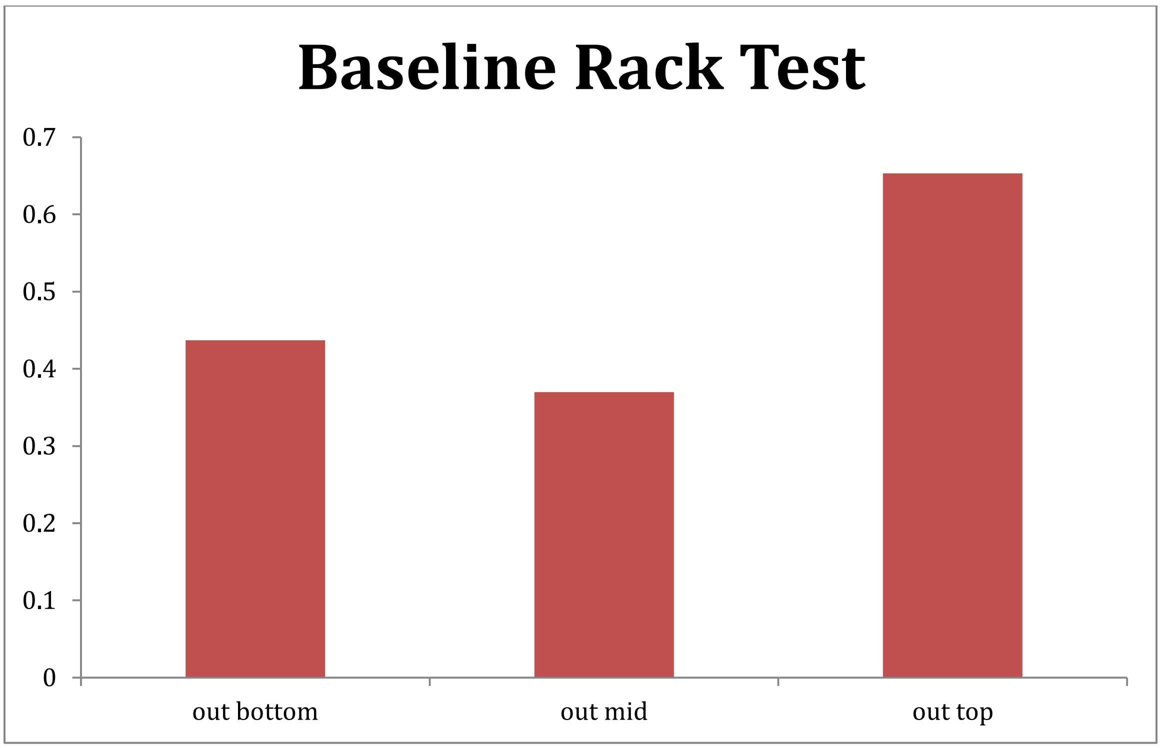


We can see that based on K values, the low temperature tests dried the slowest, while the high temperature tests dried faster. Here we see the high temperature, no-air test drying the fastest, while the high temperature airflow test dried at half the rate. Since average temperatures were not exactly the same for low-temperature or high-temperature tests, it is hard to say from this data whether airflow had an effect on drying rate.

Drying time results display similar findings. In the figure above, we can see that high temperature tests had the shortest drying time, while low temperature tests had the longest drying times. If we extrapolate, we can see that airflow slightly lowered drying times as compared to non-airflow tests.

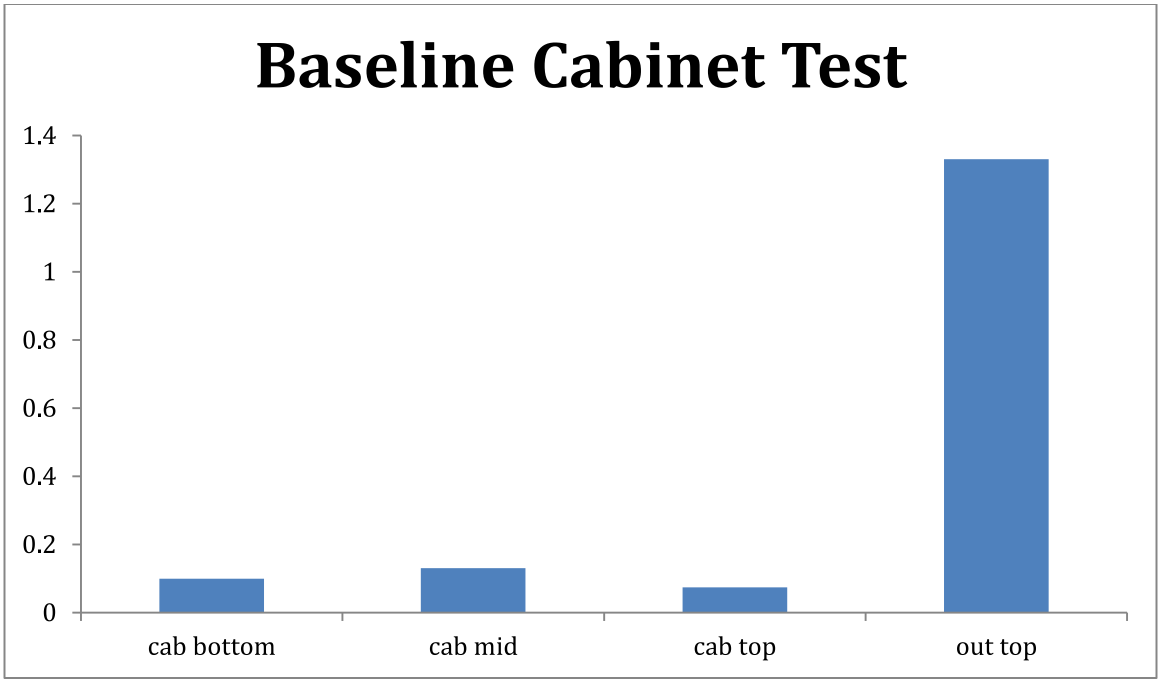
Baseline Testing

In the first series of tests performed, the cabinet and rack drying rates were measured. The first test measured the drying rates of the outdoor racks, where trays on the top, middle, and bottom of the rack were measured. Their drying rates are displayed in the graph below.



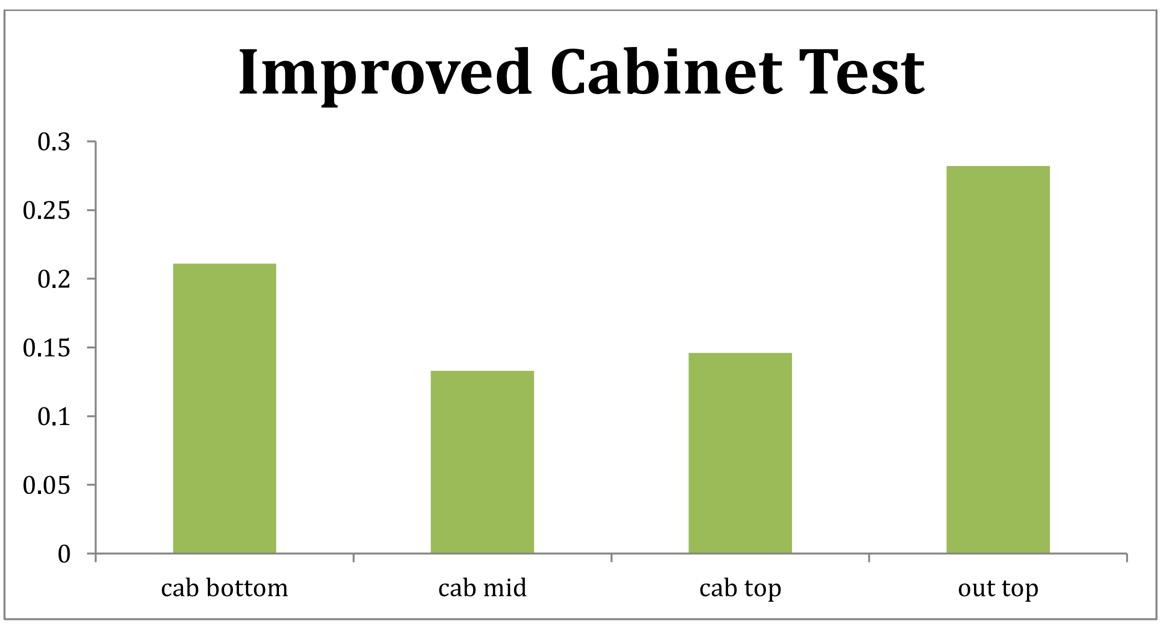
We can see that the top tray dried the most quickly, followed by the bottom and then the middle trays.

In the next test, the cabinet was used and was compared to the top tray on the outdoor racks as a control.



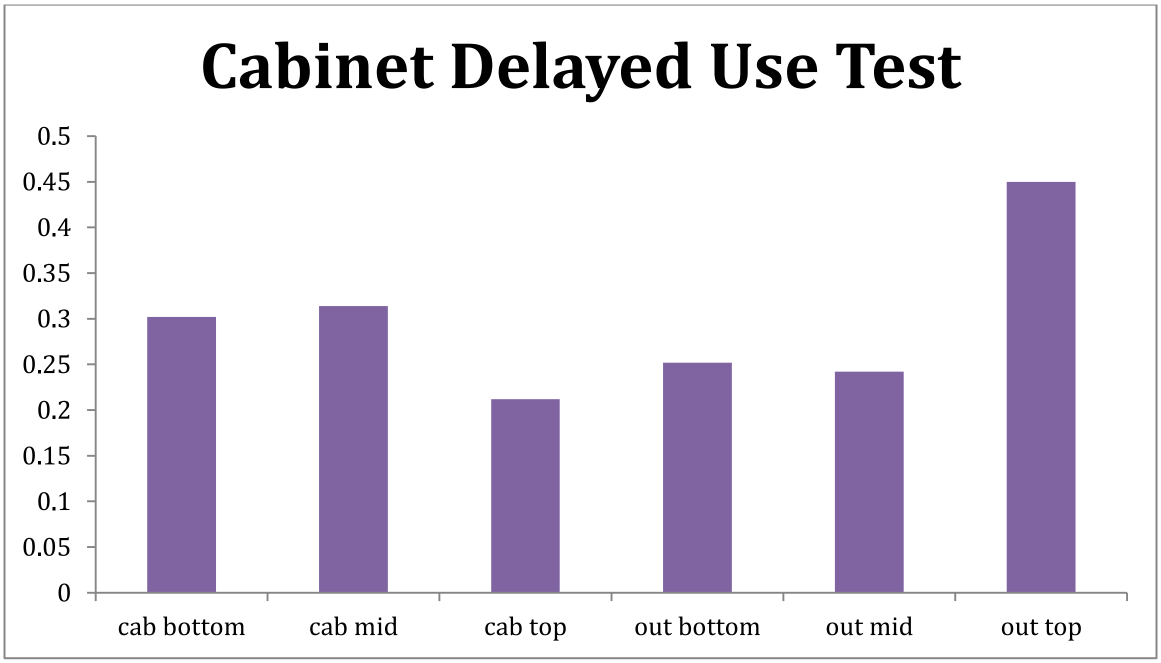
Here we see little variation in the cabinet rates, which were significantly slower than the outdoor drying rate.

Improved Cabinet
Once the cabinet was improved to allow for more direct heating, SmartDryer system use, and sun infiltration through its walls, a second test was run. This time, the cabinet performed similarly to the outdoor drying.



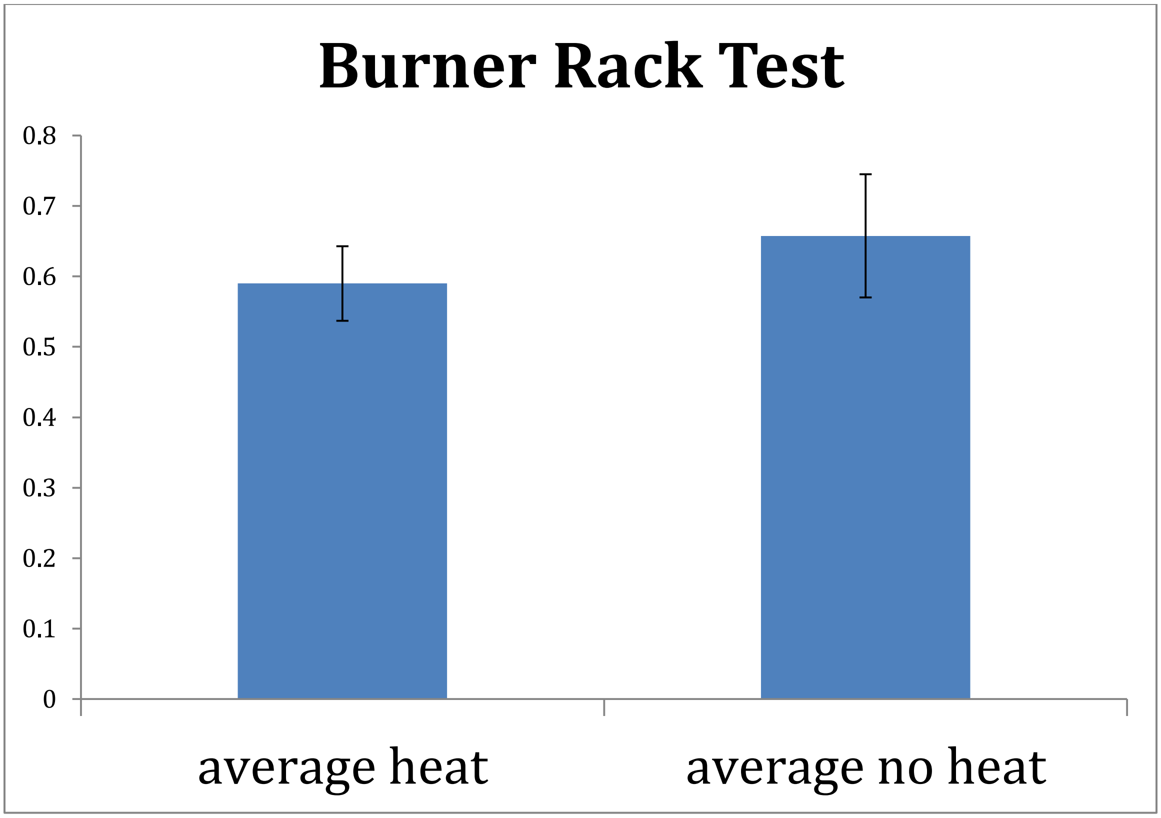
Delayed Use

In the delayed use test, we were able to compare cabinet drying to overall rack drying. Since only a fraction of briquettes are exposed to the top rack, while most are in the middle or the bottom, we decided to use top, bottom, and middle outdoor racks as comparisons. With delayed use (data collection beginning three days after initial extrusion), we can see that drying rates are much closer to each other. While the top outdoor rack (out top) is still the fastest drier, the middle and bottom cabinet racks barely out-perform the middle and bottom outdoor racks. While these data were only collected once and the difference is probably not significant, this shows that with delayed use, the cabinet system works better.



Overnight Stoves

The overnight stove test was completed multiple times, allowing for error to be calculated. Here, the difference in mass overnight for trays of briquettes was calculated. A larger mass difference implies that more drying has occurred. We expected for heated briquettes to lose more mass overnight; however, from the data we can see that the nonheated briquettes actually dried more overnight than the heated briquettes.



Discussion

MIT Testing

We saw that regardless of airflow, briquettes heated to higher temperatures dried more quickly than briquettes at low temperatures. However, tests were run during the fall and winter in Boston, where ambient humidity levels are very low. Thus, we were not sure whether these results would translate directly to Tanzania, where relative humidity levels averaged around 70% daily, which is much higher than those in Boston in the winter. We knew it was possible that results might change depending on the humidity conditions.

Baseline Testing

In rack baseline testing, we saw that the top rack performed better than the middle and bottom racks, with the middle rack performing the worst. This makes sense, since the bottom rack is exposed on the bottom, while the middle rack has briquettes both above and below it. This means that the middle rack is in a very humid environment, as it is exposed both above and below to the humidity generated by the surrounding briquettes. Additionally, the top rack is exposed to direct sunlight during the day, so briquette temperatures were able to rise more, promoting faster drying.

In cabinet baseline testing, we saw that the outdoor racks outperformed the drying cabinet, with a drying coefficient almost seven times as large as the cabinet's coefficient. The cabinet system seemed to be holding in more humidity than the outside air, making mass transfer of water from the briquette to the air more difficult due to the decreased driving force. Additionally, most of the heat gathered on the black outsides of the cabinet was not transferred into the cabinet, so its interior was cooler and damper than the outside air, making extremely suboptimal drying conditions. Temperatures in the cabinet and on the drying racks were fairly similar, while relative humidity was much lower on the outdoor top racks. This shows us that the humidity inside the cabinet was likely causing the lower drying rate.

Improved Cabinet Testing

In the improved cabinet test, the cabinet performed similarly to the outdoor racks, but not better than them. Unfortunately, it is very difficult to compare the results of this test to the results of the preliminary cabinet because the weather was very rainy and cloudy during this test, while it was sunny and warm during the first. It is possible that had there been sunny weather during the improved cabinet test that results would have been different based on the significantly different weather, which we could not control for. Thus, it is hard to say how much the cabinet improvements really improved the drying rate. Additionally, the SmartDryer system that we put in place for the improved cabinet testing stopped working overnight on the first night, because one of the sensors became too wet with dew, so the fan was never signaled to turn on during that night and additional humidity built up.

Delayed Use Testing

In the delayed use test, we allowed large amounts of moisture to evaporate from the briquettes on the outdoor racks for the first three days, then transferred briquettes to the cabinet. In this test, we saw that the cabinet performed slightly better than the outdoor racks, excluding the top rack which, as usual, dried much faster than those in any other position. This is exciting, because although it does not show a significant improvement in drying time, it could present possible solutions for drying during the rainy season. It shows that it may be possible for briquettes to dry at the speed of an outdoor rack system, but with the protection from rain that the cabinet allows. This would just require briquettes to be laid to dry under the roof for the first three days, which may or may not be possible depending on the charcoal production rate.

Overnight Stoves

The overnight stoves test showed that heated trays actually lost less mass overnight than unheated trays. This could be because when charcoal combusts, it releases water vapor, so although the heated briquettes may have been at higher temperatures, they were also exposed to excess vapor, which hindered their drying. It is also possible that the heat dissipated before it reached the briquettes above it.

Temperature and Relative Humidity Data

Conclusions

In general, it appears that even after significant improvements, the cabinet dryer still does not perform as well as the outdoor drying racks. Thus, scaling up the cabinet drying system does not makes sense, because it will take up more space and have less capacity than the current rack system. One idea that might make sense to scale up would be a large green-house type room that could aid drying during the rainy season. However, based on the results of this study, the same rate of drying could be achieved by simply adding a roof over the current drying racks during the rainy season.

Secondly, we found that the top outdoor rack dries much more quickly than any other rack, most likely due to its exposure to sunlight. It may speed drying to load the bottom level of each rack first, then load the level directly above it only after every bottom rack has already been filled, so that each tray of briquettes has at least some exposure to direct sunlight.

Third, we found that middle racks have higher humidity and dry slower than bottom and top outdoor racks, meaning that the spacing between levels may be too small. Further experiments where every other level on the rack is loaded (and levels in-between are left empty) could tell us whether a rack with more space between levels would improve drying time.

Finally, we saw that humidity increased drastically overnight, when tarps were added onto drying racks. This humidity may be decreased if, instead of placing tarps directly onto the racks, an awning that could protect from rain without going in between the racks could be used. This would allow wind to continue to penetrate the briquettes without the risk of rain eroding them.