Performance Testing of a Portable Stored Solar Thermal Energy Cooking System:

Household Energy Without Fuel, Fire, or Emissions

Matthew Paul Alonso, Keilin Jahnke, Catherine Zhou, and Dr. Bruce Elliott-Litchfield

University of Illinois Urbana-Champaign, Urbana, IL, U.S.A

Email: b-litch@illinois.edu

1 Abstract

Purpose This research was motivated by the global need for a cooking method without fuel, fire, or emissions and that respects cultural norms and cooking traditions. The stored solar thermal cookstove prototype discussed in this paper is designed to allow: cooking at any time or place; replacement of fuel and fire in most cooking systems; and operation at temperatures that emulate fire cooking. The purpose of this paper was to quantify the performance of a stored solar thermal energy system. Tests measured (a) time-temperature relationships during solar heating of a vessel containing thermal storage materials up to temperatures of 300-400°C (570-750°F) and (b) the recovery of energy from the storage vessel using a water heating test. A water heating test was chosen to provide an intuitive indication of performance.

Results Vessels containing 5 kg of potassium nitrate were heated with low cost, commercially available, 1.5 m^2 parabolic solar cookers. The energy storage vessels were fully heated in an average time of 2 hours and 21 minutes. During energy recovery testing, the solar charged vessels heated an average of 7 L of water, totaling about 2.3 MJ of useful cooking energy. The first liter of water reached "boiling" temperature (95°C) in an average of 3 minutes and 40 seconds.

Conclusions Solar thermal energy can be collected and stored in portable vessels and used to heat several liters of water. The results are promising for the development of stored solar thermal energy systems for cooking and other small-scale uses of thermal energy including space heating, food processing, charging cell phones and lighting. Further work is expected to improve solar charging time, to the optimize energy storage and system efficiency, and to study its acceptability to users.

Keywords: solar cooking, solar thermal storage, phase change, energy storage, latent heat

2 Introduction

According to the World Health Organization, 3 billion people use solid fuels such as wood, animal dung, and charcoal as their primary fuel source. The emissions from burning these fuels contribute to over 4 million premature deaths a year from stroke, ischaemic heart disease, chronic obstructive pulmonary disease, and lung cancer [1]. 460,000 of these deaths are children under 5 who succumb to pneumonia [9]. In addition, 119 million disability adjusted life years (DALYS) are attributed to the global cooking problem [16]. The burning of solid fuels is a public health emergency in energy impoverished areas. The problem is not just isolated to those cooking in their homes, but the health impacts are intensified in urban areas where multiple people are using solid fuels. This increases the particulates in the air and impacts entire communities of people, even those cooking on lower impact fuels like natural gas.

In addition to the direct health impacts, cooking fires produce key global warming agents including carbon dioxide, black carbon, and ozone precursors. Reducing these emissions can have an immediate effect on reducing the damage globally due to climate change. Residential solid fuel cooking is responsible for one-third to one-half of global black carbon or about 10% of global climate forcing, while the CO2 from these fires account for a further 10-20% [18]. Cooking fires are typically energy inefficient, exacerbating their impact on climate and human health. Though individual fires are small, the cumulative effects are sizable, and the personal, environmental, and public health impacts are tragic.

2.1 Solar as a Solution

The energy impoverished typically live in communities with limited or unreliable energy solutions. Even when people can afford to pay for cleaner fuels, the infrastructure is often not available. For some, wood is attractive because it is nearby and available for free or at a very low cost. However there are also areas where solid fuels must be purchased. The Global Alliance for Clean Cookstoves and the World Bank estimate over 1 billion people currently pay for wood, charcoal, and coal. Overall they estimate solid cooking fuels to cost on average between $100-250 USD/year, with some charcoal users spending up to $35/month. They estimate an average of 7% of household income is spent on cooking and lighting fuel, while this increases to 10-20% for lower income households [13]. The Asian Development Bank estimates that the poor spend between 25-30% of their household income on meeting their daily energy needs [8]. In addition, lost economic productivity and health expenses can increase these costs.

Traditional solar cookers are typically segmented into three categories: box type cookers, panel cookers, and concentrating cookers. As the industry has developed, these different segments have been blending together. Box type cookers now use additional panels to focus more light into the box and panel cookers have added bags and containers to trap and retain heat, making box cookers more like panel cookers and panel cookers more like box cookers. While these classifications can be useful in comparing solar cookers of similar shapes and basic concepts, it may be more important to consider the style of cooking. Box and panel type cookers typically reach temperatures just above the boiling point of water and are meant to be used in a set and forget cooking configuration, such as when cooking stews and soups. They store low amounts of energy and can keep food warm while the sun sets but cannot cook additional food during the evening. Parabolic and other concentrating cookers are ideal for high temperature cooking activities such as frying, but only have energy available while the sun is out and can cast a strong shadow. Although the high heat closely resembles cooking on a gas or wood fire, the user typically has to remain outside during use.

In general solar cooking requires being outside in the sun with a parabolic cooker, waiting several hours for food to cook unattended and in an unfamiliar way with a box or panel type cooker, or expensive setup costs to transfer solar energy indoors. Although these are useful strategies for solving the global cooking problem, the behavior change necessary to adopt these technologies have been unacceptable for many individuals, even when solar cookers have been distributed at little to no cost. This has led to an abandonment rate of solar cooking technologies of up to 90% globally [13].

Despite the challenge of developing an effective solar cooking solution, the sun is abundant and available in many of these same areas and can provide a lower cost solution without the dependency on a national grid, which often are not financially feasible. This work investigates using solar energy as a partial solution to this energy problem through the development of solar thermal storage. This technology can provide a clean source of energy on sunny days and the energy can be stored and used that evening after the sun has set and potentially several days after.

2.2 Adoption Factors

In-person interviews conducted in India and the US, along with phone and video interviews conducted in India, Uganda, and the US validated previous conclusions from failed solar energy interventions and information shared by NGOs [2]. Users typically wanted to be able to cook inside their home and cook rapidly. In certain regions, lifestyles also conflict with when the sun is available as many people work when the sun is high in the sky. Other individuals are not accustomed to cooking during midday. In the state of Tamil Nadu in India for example, cooking often occurs in the late evening after the sun has set and in the very early morning before the sun rises. Many households had 2-3 stove options as electricity, gas, and kerosene supplies were unreliable. A snapshot of cooking stoves in the Indian states of Tamil Nadu and Haryana can be found in figures 1, 2, and 3. Potential users aspired to improve their cooking situation and desired a cooking utensil that provided a feeling of improved social status.

The focus on low cost devices instead of high value devices led to a wide variety of solar cooker designs that have seen limited use and adoption. Solar Cookers International has been documenting solar cooker designs through a solar cooking wiki that currently lists almost 400 products and designs [15]. Many are do-it-yourself designs and tend to be perceived as being designed for "the poor" [12]. This perception reduces their adoption. Other devices, available commercially, can be aesthetically pleasing but are typically expensive and may not meet the cooking performance expectations of the user.

In 2013, Otte proposed a set of of variables that influence the adoption of solar cookers. Her hierarchy focuses on environmental factors (space availability, solar insolation, and the cost and availability of cooking fuels), cultural factors (preferred food characteristics, cooking habits, and daily cooking schedule), technical factors (performance, ease of use, and repairability), social factors (motivation for adoption - economic, health, and or environmental, perception of the technology, and power relationships in the community), economic factors and the political policies that affect them [12]. A device can fail by not meeting one set of these factors. Previous technology developers have focused on the technical ability to cook food, without an emphasis on the cultural factors of potential users. The solution described in this paper is intended to address the cultural factors by providing energy storage to tackle the daily cooking schedule. Preferred food characteristics and cooking habits will be satisfied by tuning the system to work at high temperatures to provide the ability to sear, deep fry, pan fry, bake, and boil food using the tools and methods they are familiar with.

A method to store solar thermal energy for use at night is a major industry goal. The non-governmental organization, Climate Healers, released a challenge in March of 2011 for the engineering community to develop a solar cooker that works at night[14]. They identified this as the missing component to make solar cookers work in rural India. Cuce et al 2013 reviewed several solar cooking technologies and identified the inability to cook at night as the most challenging issue to address [4].

Figure 1: Wood stove setups observed in the state of Tamil Nadu in India

Figure 2: Animal dung cookstoves observed in the state of Haryana, India

Figure 3: Fuel and electric stoves in Tamil Nadu and Haryana. Beginning at the top left and working clockwise the pictures are an example of a kerosene stove, electric resistance stove, an induction cooktop, a gas range, and an additional kerosene stove.

2.3 Cooking at Night

Solar energy storage designs are available that have been tuned to cook like traditional solar cookers, holding the system at a temperature near 100 °C for several hours [4]. These systems provide just enough heat to pasteurize liquids and tenderize meats and vegetables. A majority of these systems utilize traditional box cookers with an insert containing an energy storage material. Low temperature storage systems provide an acceptable option for areas with limited direct sun and who typically boil or slow roast their food.

Lecuona created a portable system for use with a parabolic dish [6]. They used two concentric cooking pots, where they stored phase change material in the outside pot and cooked in the interior pot. The pot is supported at the focal point of the parabolic dish when it is being heated by the sun. An insulated storage container is kept inside the home to store the device once it is hot. The system without water, weighed 8.7 and 11.1kg and required 1MJ and 2.8MJ of energy to fully melt the paraffin and the erythritol respectively. The total charging time from ambient was not reported. Lecuona created a 1-D model that predicted the system could cook three meals a day. In addition, they predicted it could store and retain heat for a longer period of time if it was heated without water. In their follow up paper identifying several figures of merit for heat storage, they indicate their system could cook or keep food warm for up to 30 hours before it would need to be reheated [7]. This system allows the user to cook inside their kitchen and like similar low temperature systems, it is used to boil food.

Stationary cooking systems have been designed to be either located outside the home or transfer the energy from outside into the home. The Norwegian University of Science and Technology (NTNU) have created several stationary system designed to charge a

$KNO_3/NaNO_3$ salt mixture including an air-pebble bed system, a parabolic trough with a thermal siphoning oil loop, and a parabolic dish system that utilizes a steam loop to charge. These systems track the sun and and do not require intervention by the user. The systems have charging times between 4 and 5 hours. When fully charged, the systems took over 32 minutes to fry an egg (air system) and 38 minutes to boil a liter of water (oil system) [10, 11, 17].

NTNU has also demonstrated a portable system using the same $KNO_3/NaNO_3$ mixture as the stationary systems. Foong reported on the design and modeling of the system. It used .5kg of the PCM mixture and was charged to 230-260C in 2-2.5 hours [5]. Continuing on this work, Vermachi increased the mass of the PCM mixture to 7.5kg. This increased the heating time of the system to about 4 hours. They calculated 5 MJ of the 38 MJ collected were stored in the system, for an efficiency of 13%. No discharge or cooking performance data were reported so it is unclear how much of this energy would be useful for cooking.

Research on solar thermal energy storage for cooking applications is still developing. There is not a defined standard for reporting information to compare systems and measure improvements. This makes it difficult to evaluate the performance of the above systems. It was clear that there was a need to improve cooking performance. Section 3.3 outlines one approach to measure the system performance and provide an indication to users how the system will perform the most basic of cooking operations, boiling water.

3 Materials and Methods

This study details the fabrication method for constructing portable stored solar thermal vessels, quantifies how quickly we can store thermal energy in a portable energy storage device using unmodified parabolic dishes, and discusses how much energy can be recovered from the system. A water boil test was used to provide an intuitive metric to understand the system performance.

3.1 Materials

The following is a comprehensive list of the materials used to construct and test the solar thermal energy system described in this paper:

1. Parabolic cooker from Eco-Worthy - 1.5 m^2 Parabolic Concentrator
2. NI CompactDAQ 4-Slot USB chassis with 2 16-channel thermocouple input modules
3. Omega RDXL4SD 4 port thermocouple data logger
4. Omega K-type, glass braid, 20 gauge thermocouples (5SRTC-GG-K-20-72)
5. Omega OB400 thermocouple cement
6. Potassium nitrate (001/06-US), refined grade in prill form from SQM North America
7. 8"x4" 16 gauge, anodized aluminum round cakepan
8. Rust-Oleum Bar-B-Que Black Satin High Heat Spray Paint, Model 7778830
9. SOLKOTE HI/SORB-II from the Solar Energy Corporation (www.solec.org)
10. MP-200 Pyranometer separate sensor with handheld meter from Apogee Instruments
11. 3/8" male pipe - hex socket plug
12. 6061 10"x6’x.25" aluminum sheet
13. 3” and 6" OD x .25" 6061-T6 extruded aluminum tube
15. Pyrogel Xt-E High temperature insulation

3.2 Vessel Fabrication

The energy storage system is composed of 4 components; the heat transfer unit (1 plate and 2 concentric tubes), the energy storage material, a containment vessel, and the insulation. The system contains 5 kg of KNO_3, 2 kg of aluminum, and 1.5 kg of insulation. After assembly, the cooking surface is 22.6 mm in diameter and the complete system is 30.5 mm in diameter by 15.25 mm tall. The vessel is insulated on the sides and bottom with 50 mm of Pyrogel insulation. An outer covering of aluminum foil was used to reduce convection losses through any gaps in the insulation and to mitigate the dust generated by disturbing the insulation. An attempt was made to seal the vessels with aluminum pipe plugs, but they proved to be insufficient during solar heating and eventually leaked molten salt. K-type thermocouples were attached with thermocouple cement at the locations indicated in figure 4. A surface coating was applied to the exposed surface of the vessel to enhance the solar absorption. Either BBQ paint or SolKote was applied per the manufacturers directions. SolKote is designed to have a lower emissivity (.5) than absorptivity (.95). The BBQ grill paint has the same emissivity and absorptivity (.98).

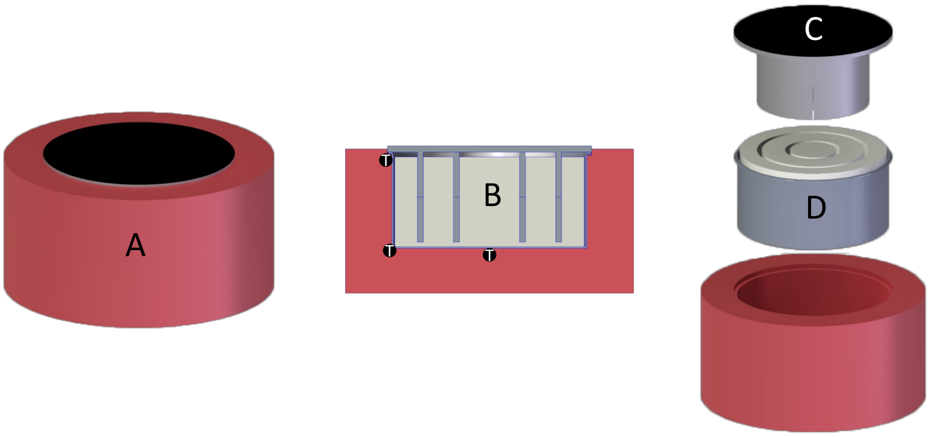

Figure 4: External, cross section, and exploded view of the storage system. The 4 main system components are labeled: (A) Pyrogel XT-E (B) Thermal storage material, KNO3 (C) 6061 Aluminum plate and tubes (D) Aluminum container. Three thermocouples (T) in the cross section view are referenced counterclockwise starting at the top left as the plate, side, and center thermocouple.

3.3 Methods

The testing site for this study was chosen based on data from solar insolation maps and weather forecasts. Nashville, Tennessee was selected as it was expected to have several days of sunshine and historically had higher solar insolation than similar areas with expected sunshine. The tests were carried out from October 5th through October 7th, 2015. Three 1.5 m^2 parabolic solar cookers were setup as recommended by the manufacturer. The parabolic dishes were unmodified and spaced sufficiently apart so that they would not cast a shadow on each other during the duration of a test. A picture of the setup is shown in figure 5. Twelve vessels were fabricated as described in section 3.2. Four thermocouples were connected to a portable datalogger to record temperature data during charging. Three of the thermocouples were cemented to the vessel and one was used to measure ambient air temperature. Solar irradiance data and temperature readouts from the data loggers were recorded manually by the user every 15 minutes during testing. The energy storage material inside vessel was considered completely melted and the vessel was "charged" when the center thermocouple reached 340°C.

The vessel was then removed from the parabolic cooker and the thermocouples were transfered to a separate data acquisition system for the modified water boil test. Three thermocouples from the vessel and an additional K-type thermocouple for the water were used to record the temperature of the system as it heated successive 1L volumes of water from ambient temperature to 95°C. At 95°C, the water was removed and replaced with fresh water. The test was concluded when the water temperature failed to reach 95°C and began to decline.

Figure 5: Experimental setup for the charging tests.

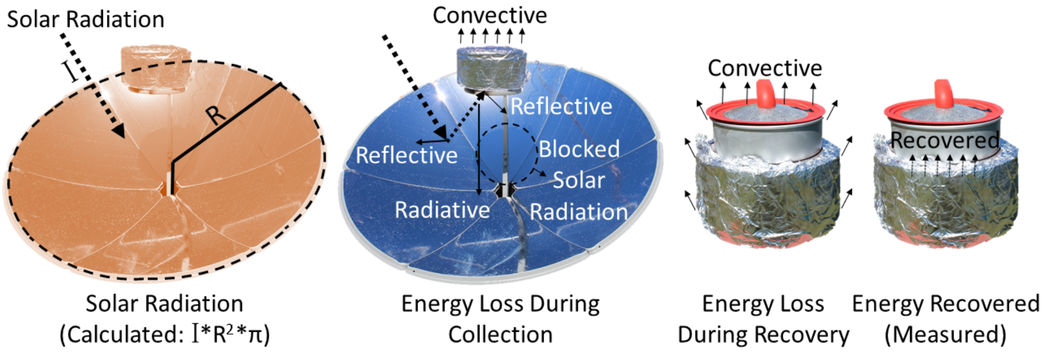

Figure 6: The efficiency of the system is being measured by the total amount of energy recoverd in the water divided by the total available solar radiation. This figure notes where energy is being lost in this process.

The solar irradiance and water boil test data were used to calculate the efficiency of the stored solar thermal energy system. Figure 6, provides a graphical description of how energy is transferred in the system. The efficiency of the system was calculated as follows:

$$SystemEfficiency = \frac{EnergyRecovered}{AvailableSolarRadiation} \tag{1}$$

where the available solar radiation in megajoules (MJ) was calculated from the solar irradiance data and represents the amount of sun shining over the area of the dish while the vessel was charging.

$$AvalailableSolarRadiation = (Radiation_1 * t_1 + ... + Radiation_n * t_n) * A_{dish} \tag{2}$$

where the solar irradiation measurement, $Radiation_i$, is in MW/m^2, the time t_n is in seconds, and the A_{dish} is in m^2. This value provides an estimate for the maximum amount of solar radiation that could have been collected, rather than the actual amount of solar radiation concentrated and collected into the vessel. This provides a fair means to compare systems with more efficient charging mechanisms.

The energy recovered was calculated by:

$$EnergyRecovered = (m_{water_1} * DeltaT_1 + ... + m_{water_n} * DeltaT_n) * C_{p_{water}} \tag{3}$$

where $DeltaT_i$ is the change in water temperature for each successive liter of water, m_{water} is the mass of 1L of water for each test, and C_p is the heat capacity of water in MJ/kg°C. The final heating attempt was included in equation 3 whether it reached 95°C or not.

4 Results

Over the course of three days, 26 attempts were made to charge the KNO_3 vessels. Four of the experiments were excluded because the test was ended before the vessel reached 340°C and insufficient time was available to complete the water boil test. Two more were excluded because they were removed from charging before reaching 340°C.

4.1 Charging Results

The solar irradiance during charging averaged 958 W/m^2 with a minimum of 817 W/m^2 and a maximum of 1006 W/m^2. The 12 vessels were tested a total of 20 times and spent on average 141 minutes charging. Figure 7 shows an example charging curve for the vessel. At approximately 9:15 a leveling off of all three thermocouples can be observed as KNO_3 undergoes a solid-solid phase transition. At 11:00, the plate temperature decreases because a large cloud blocked the sun and the top plate began cooling. A majority of the vessels leaked between 5 to 50 grams of KNO_3 during a single charge cycle. The aluminum plug became soft during fabrication and may have prevented adequate tightening of the plug, allowing salt to be discharged from the vessel. While this initially design allowed the systems portability to be tested, it has since been replaced with an improved method that eliminated the leaks.

4.2 Recovery Results

Overall, an average of 2.3 *MJ* of energy was recovered from each vessel, boiling 7-8L of water. This neglects the energy remaining in the vessel and any energy lost due to evaporation. Table 1 shows the average time from ambient temperature to 95 °C for the first 5L of water for the 20 tests conducted. After 5L, vessel performance was less predictable and dependent on the specific charging conditions for that vessel. Figure 8, shows an example of the temperature characteristics of the vessel during a recovery test. While the vessel was removed when the center thermocouple reach 343 °C, the vessel equilibrated to 350 °C. Since the initial temperature of the plate and side thermocouples were slightly above 340 °C, this test would be expected to boil the average number of liters of water. If the plate and side thermocouple were much higher than the center thermocouple, it would likely be able to boil an extra liter or two. In this case, 7 L of water were boiled and the 8^{th} liter was heated to 93 °C.

The average system efficiency for the 20 tests conducted was 19%. For morning tests that began after 8 am and finished charging by 12 pm, the average system efficiency was 17.9%. For midday tests that began after 11am and concluded by 2pm, the average system efficiency was 21.6%. Using a Welch Two Sample t-test ($n_{morning}$=8, n_{midday}=7, t=-3.2882, df=10.519, p-value=0.007654), there was a significant difference in results between the two testing periods. This can be expected as solar irradiation values were increasing between these two time periods and a better focus was achieved with the parabolic dishes tested during midday.

Only the morning test had enough samples to compare the performance of the surface coatings. The average efficiencies were 19.5% and 16.9% for the SOLKOTE and BBQ paint respectively. Using a Welch Two Sample t-test (nbbq=5, nsol=3, t=-3.7894, df=4.315, p-value=0.01678), the SOLKOTE coating had a significant impact on the system efficiency. Similar improvements were observed for charging time and system efficiency in general, but the significance could not be confirmed using statistical analysis.

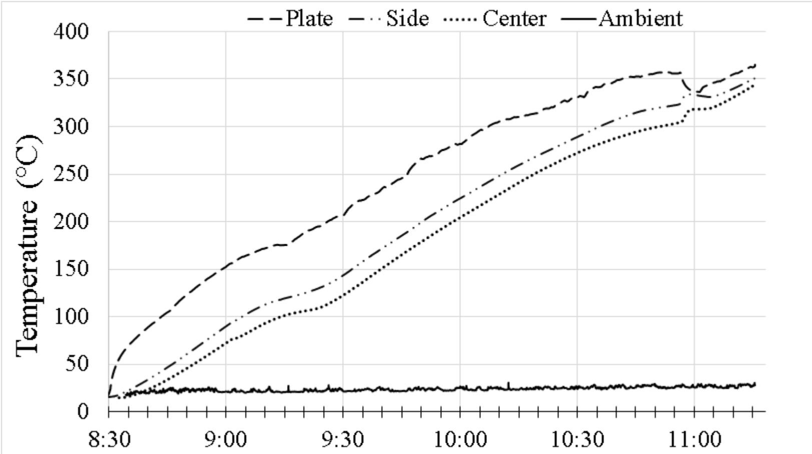

Figure 7: Sample output data from vessel charging. Vessel was charged on October 7th, 2015 from 8:30 am to 11:15 am.

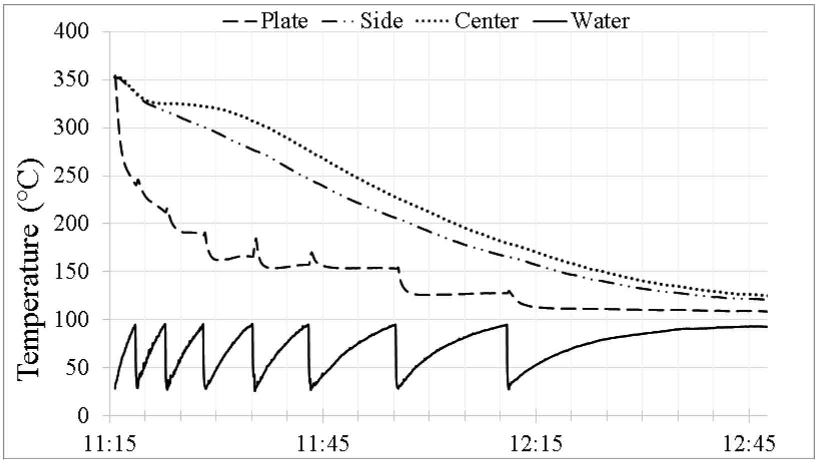

Figure 8: Sample output data from the water boil test. Seven liters of water were boiled with an eighth liter approaching 95 °C. Vessel was charged on October 7th, 2015 from 8:30 am to 11:15 am. This is the same vessle used in Figure 7.

Table 1: Average time (mm:ss) to boil for each successive liter

	1st	2nd	3rd	4th	5th	5L Total
Average	3:40	4:25	6:00	7:27	8:40	30:13
Standard Deviation	1:14	1:31	1:34	1:20	1:30	6:18

5 Conclusions

Solar thermal energy can be collected and stored in portable vessels and used to heat several liters of water. The vessels described in this paper have been used to fry meats, vegetables, and flat bread; cook soups and stews; charge electric devices; and dry corn. They can be charged using commercially available parabolic dishes in about 141 minutes and at their peak charge, boil 7-8 liters of water. They have been shown to release over 2MJ of energy in a useful manner, with an efficiency of approximately 19%. The results are promising for the development of stored solar thermal energy systems for cooking and other small-scale uses of thermal energy. Further work is expected to improve solar charging time, to improve energy storage time and system efficiency, and to study its acceptability to users.

Acknowledgements

This work was funded by the Institute for Sustainability, Energy, and the Environment at the University of Illinois Urbana-Champaign and the authors are appreciative of their continued support. Thank you to the many students who have contributed to this work through class projects and undergraduate research. Finally, we would like to thank the communities around the world who have shared and continue to share their life experiences with our team.

References

[1] "WHO | Household air pollution and health," *WHO*, Mar-2014. [Online]. Available: http://www.who.int/mediacentre/factsheets/fs292/en/. [Accessed: 17-Apr-2014].

[2] B. Ahmad, "Users and disusers of box solar cookers in urban India—: Implications for solar cooking projects," Solar Energy, vol. 69, Supplement 6, pp. 209–215, Jul. 2001.

[3] T. C. Bond et al., "Bounding the role of black carbon in the climate system: A scientific assessment," J. Geophys. Res. Atmos., vol. 118, no. 11, pp. 5380–5552, Jun. 2013.

[4] E. Cuce and P. M. Cuce, "A comprehensive review on solar cookers," Applied Energy, vol. 102, pp. 1399–1421, Feb. 2013.

[5] C. W. Foong, O. J. Nydal, and J. Løvseth, "Investigation of a small scale double-reflector solarconcentrating system with high temperature heat storage," Applied Thermal Engineering, vol. 31, no. 10, pp. 1807–1815, Jul. 2011.

[6] A. Lecuona, J.-I. Nogueira, R. Ventas, M.-C. Rodríguez-Hidalgo, and M. Legrand, "Solar cooker of the portable parabolic type incorporating heat storage based on PCM," Applied Energy, vol. 111, pp. 1136–1146, Nov. 2013.

[7] A. Lecuona-Neumann, J.-I. Nogueira-Goriba, and R. Ventas-Garzón, "Solar cooking with heat storage: experiments using PCM and figures of merit for solar cookers," in International Conference on Advances in Solar Thermal Food Processing, Faro, Portugal, 2016.

[8] J. Masud, D. Sharan, and B. N. Lohani, "Energy for All: Addressing the Energy, Environment, and Poverty Nexus in Asia," Open Access Repository, Apr. 2007.

[9] V. Mishra, "Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe," International Journal of Epidemiology, vol. 32, no. 5, pp. 847–853, Oct. 2003.

[10] M. Mussard, A. Gueno, and O. J. Nydal, "Experimental study of solar cooking using heat storage in comparison with direct heating," Solar Energy, vol. 98, Part C, pp. 375–383, Dec. 2013.

[11] D. Okello, C. W. Foong, O. J. Nydal, and E. J. K. Banda, "An experimental investigation on the combined use of phase change material and rock particles for high temperature (~350C) heat storage," Energy Conversion and Management, vol. 79, pp. 1–8, Mar. 2014.

[12] P. P. Otte, "Solar cookers in developing countries—What is their key to success?," Energy Policy, vol. 63, pp. 375–381, Dec. 2013.

[13] V. R. Putti, M. Tsan, S. Mehta, and S. Kammila, "The State of the Global Clean and Improved Cooking Sector," Energy Sector Management Assistance Program and the Global Alliance for Clean Cookstoves, Technical Report 96499, May 2015.

[14] Rob Goodier, "Challenge: Make a solar cooker that works at night," Engineering For Change, 01-Mar-2011. [Online]. Available: https://www.engineeringforchange.org/challenge-make-a-solar-cookstove-that-works-at-night/. [Accessed: 01-Jan-2013].

[15] SCI, "Solar cooker designs," Solar Cookers International Network, Oct-2016. [Online]. Available: http://solarcooking.wikia.com/wiki/Category:Solar_cooker_designs. [Accessed: 08-Oct-2016].

[16] K. R. Smith et al., "Millions Dead: How Do We Know and What Does It Mean? Methods Used in the Comparative Risk Assessment of Household Air Pollution," Annual Review of Public Health, vol. 35, no. 1, pp. 185–206, 2014.

[17] A. H. Tesfay, M. B. Kahsay, and O. J. Nydal, "Solar Powered Heat Storage for Injera Baking in Ethiopia," Energy Procedia, vol. 57, pp. 1603–1612, Jan. 2014.

[18] D. Zaelke and N. Borgford-Parnell, "Primer on Short-Lived Climate Pollutants," Institute for Governance & Sustainable Development, 2012.