<u>Solar Cookers and Other Cooking Alternatives</u>

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Nearly 50% of the world's population relies on coal, and biomass fuels such as wood, dung, and crop residue for domestic heating. [23] When these materials are burned inside the fumes are toxic. Health Risks include pulmonary disease, pneumonia, and respiratory infections. [10] Indoor air pollution is also associated with 1.6 million deaths per year. [23] The most commonly used biomass is wood. However, there are shortages in fuel wood. These shortages have reached crisis levels for more then 100 million people. [6] Women and children are responsible for collecting the wood needed for cooking. Each day they are forced to walk farther to find it. On these long trips women have been beaten, raped and even murdered. [23] Also 1 in 6 people live without regular access to safe drinking water. Waterborne diseases such as diarrhea, typhoid, and cholera cause 80 % of the deaths and illnesses in developing countries. [12] To solve these problems an alternative energy source is needed that will eliminate the dependence on burning of biomasses and provide a simple effective way to cook food and pasteurize water.

A potential solution is the solar cooker. A solar cooker is a simple low cost way to use the Sun's energy for cooking purposes. Solar cookers focus the Sun's energy onto a cooking vessel. The cooking vessel is painted black so that it absorbs most of the solar radiation. Also the cooking vessel is typically covered by glass or surrounded by plastic to create a greenhouse effect. The glass and plastic trap the heat around the cooking vessel and also protects the vessel from cooling air. Solar cookers can be made out of any locally available material but most are made out of wood or cardboard and are lined with a reflective material such as aluminum foil.

There are four main types of solar cookers; the box cooker, panel cooker, parabolic cooker and solar-funnel cooker (below). The box cooker is an insulated box covered with plastic or glass. It has a reflective lid that focuses light onto the cooking vessels. It is simple to use and requires little refocusing. Also it can hold and cook several pots of food at once. [7] A panel cooker has multiple reflectors. Light is reflected by the panels onto the cooking vessel which is typically surrounded by a plastic bag. It is simple to make and usually the least expensive solar cooker. The parabolic cooker focuses light to a specific focal point. This allows a small cooking vessel to reach higher temperatures and in less time then the box or panel cooker. However, since the light has to be focused the position of the solar cooker has to be turned more frequently to track the Sun's position. It typically has to be refocused every 15 minutes. Also the light at the focal point has been known to burn the hands of people using the solar cooker and can also cause eye damage. [8] The solar-funnel cooker (pictured above) was developed at BYU by Physics Prof. Steven Jones circa 1998. [11] It combines elements from the three other types and is noted for low-cost, simplicity, efficiency and safety. Details of constructing this funnel cooker are available on-line at no cost. [11]

For every type of solar cooker how well the cooking vessel heats up depends greatly on the amount of solar radiation that reaches the surface of the Earth. Here on the surface we can receive as much as 1.4 kW/m^2 of radiation. However, the amount of solar radiation received varies by latitude. The most energy is available between latitudes 25°N and 25°S. Most of Africa, Asia, South America, and Central America are between these latitudes. [8] Therefore, many developing countries are located in this area where solar cookers will function the best.

Solar Cookers are currently in use in over 50 countries. The list includes India, China, Peru, the Philippines, Guatemala, Sierra Leone, Indonesia, and many others. [18]. However, in each country the use of solar cookers is not widespread. The two countries with the largest known use of solar cookers is China with 100,000 and India with 500,000. [18] However, these numbers are quite small since both China and India have a population of over 1 billion, millions of which are living in poverty. For solar cookers to become a viable solution to the problems mentioned the use of solar cookers needs to drastically increased.

There are many reasons for the limited use of solar cookers in developing countries. First of all there is a lack of funding, which makes it difficult to widely publicize the use of solar cookers. [4] The use of solar cookers is instead being spread slowly from village to village. Another reason for the lack of use is that cooking with fire has been a long standing tradition, and in many countries there is a strong cultural resistance to change. In villages that have been introduced to solar cookers, unless the people are taught how to use solar cookers, and incorporate them into their daily lives people will quickly revert back to old cooking practices. Community programs are needed so that the solar cookers will be used on a long term basis. [5] Some people might also be resistant to adapt the solar cooker because the sun is not always shining therefore solar cookers can not always be used. Another cooking option is needed in addition to the solar cooker. The lack of solar cooker use is also due to the fact that solar cookers cost money which people in developing countries do not have, and solar cookers that are inexpensive are not always durable or efficient. Finally there is a widespread belief that technology is the solution to our problems. It is hard for people to accept the idea that something as simple as a cardboard box can be a solution to serious problems that exist throughout the world. [5] To increase the use of solar cookers more effort and research is needed. Further research is needed in creating low cost durable solar cookers. Also research is needed in improving their efficiency, and expanding their uses. Feasible alternatives need to be found for when the sun is not shining and the solar cooker can not be used. Finally, the most important thing that needs to be done is to inform and educate people about the benefits of solar cooking.

My research this summer involved many different areas of solar cookers. The first area of solar cookers I tested was their efficiency in heating. I conducted my heating tests outside of the Eyring Science Center at Brigham Young University between 11:30 a.m. and 1:30 p.m. I tested two solar cookers at a time. For my tests I placed 1 liter of water into a half-gallon (two-liter) canning jar that had been painted black. The lid of the canning jar had a hole in the center. I placed a thermocouple probe through this hole and secured it so that it was 1 cm below the water line. I then placed the jar on a wire stand. A wire stand was used so that sunlight could strike all surfaces of the canning jar including the bottom. Then I placed a Reynold's oven bag over the cooking vessel and the stand. I blew air into the bag so that it did not touch the cooking vessel. I then secured the bag with a twist tie. During the two hours of testing I recorded the temperature of the water every 5 minutes using a TI-CBL. To retrieve the data from the TI-CBL I downloaded it onto a TI-83 calculator. [22] I then analyzed the data using Microsoft Excel.

The first model I tested was the aluminum foil funnel. It is made from cardboard and lined with aluminum foil. It has a 60 degree opening angle. During testing I placed it inside of a cardboard box to make it more stable. Due to the elevation in Provo which is approximately 4,549 feet [14], the boiling point of water is about 97°C or 207°F. So the results for the aluminum-foil funnel show that it reaches boiling-water temperature in approximately an hour and twenty minutes.

The second type of solar cooker I tested was a mylar funnel cooker, also developed by Steven Jones. It is made out of a sheet of mylar and placed in a plastic base for stability. It has a 60 degree opening angle. A problem with this funnel is that the mylar sheet moves in the wind, which can reduce the overall heating. During my testing I found that it did not function as well as the aluminum-foil-on-cardboard funnel. It reached 90°C or 194°F after 1 hour and 30 minutes and after two hours it was just reaching the boiling point.

The next type of solar cooker I tested was a windshield-reflector funnel. It is made out of a commercially-available car windshield reflector/shade. The reflector was cut like the cardboard-funnel pattern and folded so that it formed a funnel with a 60 degree opening angle. This funnel was about the same size as the mylar and aluminum funnel. I also placed the windshield funnel into a plastic base for stability. It reached 90°C/194°F in an hour and 50 minutes. After two hours it approached the boiling point.

I next tested a larger funnel made out of a car windshield shade. [3] This funnel was made out of the entire windshield shade rather then just part of it and looks somewhat like a panel-cooker. I used a cardboard box to provide a support base. However, this cooker was extremely unstable. It continuously fell over and would tip in the wind. It did not work well at all. After 2 hours it only reached a temperature slightly greater then 70°C/158°F.

The final solar cooker I tested was a mounted-cone solar cooker. This solar cooker was made out of aluminum foil and cardboard. It was mounted on a piece of plywood so that it could be oriented towards the sun. The sides were 1 foot in length, and the base of the cone was a circle with a diameter of 1 foot. The opening angle was 45 degrees. I found that it reached 90° C/194°F in about an hour and 25 minutes, and it was almost boiling after two hours.

Overall the solar cooker that was most efficient in boiling water was the aluminum foil (on cardboard) funnel, Dr. Jones' original 1998 creation. [11] However, all the solar cookers, except for the large windshield funnel, reached 65°C/149°F within an hour. This is the temperature needed for water pasteurization. Water heated to this temperature for at least 20 minutes will kill most bacteria. [16] Therefore, most of the solar cookers function well for providing clean drinking water.

I next wanted to see if I could improve the efficiency of the best solar cooker I tested. So I conducted tests of the aluminum foil funnel using a half gallon canning jar, and two oven bags. I thought the two oven bags might better protect the vessel from the surrounding air and reduce heat loss. However, I found that two oven bags do not work as well as one. With one oven bag the water temperature would reach 90°C/194°F in an hour, with two oven bags the water temperature would reach 90°C/194°F in an hour and 25 minutes.

The second area of solar cookers I looked at was their potential use for cooling. I tested to see how effective they are at cooling both at night and during the day. During both times, the solar cooker needs to be aimed away from buildings, and trees. These objects have thermal radiation and will reduce the cooling effects. At night the solar cooker needs to also be aimed straight up towards the cold sky. During the day the solar cooker needs to be turned so that it does not face the Sun and also points towards the sky. [11] For both time periods cooling should be possible because all bodies emit thermal radiation by virtue of their temperature. [8] So the heat should be radiated outward. Cooling should occur because of the second law of thermodynamics which states that heat will flow naturally from a hot object to a cold object.[7] The sky and upper atmosphere will be at a lower temperature then the cooking vessel. The average high-atmosphere temperature is approximately -20 °C. [2] So the heat should be radiated from the cooking vessel to the atmosphere.

For daytime cooling, I always conducted my tests between 2:30p.m.-6:30p.m. on a sunny cloud free day. I conducted tests using different solar cookers, sizes of canning jars, water amounts, and types of plastic bags. I measured the water temperature using a temperature probe and a TI-CBL. The data for the ambient temperature was taken from the Brigham Young University Weather Center located at the top of the Eyring Science Center. The data was downloaded and recorded every 5 minutes. The best results I obtained are for a wide funnel with a 1 quart canning jar, 500 ml of water, and two polyethylene bags. I found that the difference between the water and ambient temperature reached approximately 2.2 °C or 4.0 °F. The cooling trend (slope) was still towards more cooling at the end of the test suggesting the need for further testing.

One possible reason that daytime cooling was not greater has to do with the different types of solar radiation. There are two kinds of solar radiation; direct and diffuse. Direct radiation is the portion of light that appears to come straight from the Sun. Only direct radiation can be focused. Diffuse radiation is sunlight that appears to come from all over the sky. When sunlight hits the Earth depending on cloud cover more or less radiation is diffused. [2] During daytime cooling I am turning the solar cooker away from the direct radiation however; I am unable to turn it away from the diffuse radiation.

The tests for nighttime cooling took place between 8:30 p.m. and 5:30 a.m. I conducted the tests on the observatory deck at the Eyring Science Center. I tested a variety of solar cookers with different types of plastic bags, water amounts and sizes of canning jars. I once again measured the water temperature using a temperature probe and the TI-CBL and I also downloaded data for the ambient temperature from the BYU Weather Center. The best results I found were for the mounted funnel with a half gallon canning jar, 1 liter of water, and two polyethylene bags. The largest temperature difference was 6.0°C or 10.7°F. Again, the cooling trend was towards still cooler temperatures at the end of the tests. If at night the temperature was within 6 °C or 10°F of freezing, nighttime cooling could be used to create ice. Previous tests at BYU (in the autumn and with less water) achieved ice formation by 8 a.m. when the minimum ambient night-time temperature was about 48 °F.

The next area I researched was retained heat-cooking. When we normally cook, after the food is removed from the heat source, the temperature decreases and cooking ceases to continue. When retained heating is used the applied heat is retained after the cooking vessel is removed from the heat source and additional cooking does take place. [17]To retain the heat, the cooking vessel is placed in an insulating container. These insulating containers are typically called hayboxes. A haybox can be made out of a box, basket, or even a hole in the ground and filled with another insulating material such as hay, straw, feathers, sawdust, rags, wool, or something similar.[15]

For my retained heating experiment I heated rocks in a funnel solar cooker for three hours. I then placed them at the bottom of a styrofoam cooler that had been lined with aluminum foil. The aluminum foil will reflect radiated heat from the cooking vessel back on to the vessel. I then placed a cooking vessel on top of the rocks. The cooking vessel had already been heated so that the water temperature was between 90-100 °C or 194-207°F. I then surrounded the vessel with shredded paper. Next I measured the decrease in the water temperature over a three hour period using a temperature probe and the TI-CBL.

What I found from performing this experiment is that retained heating is a convenient way to keep food warm and even continue cooking. Heated food needs to be kept about 60°C/140°F for it to be considered safe for consumption. My results show that retained heating keeps food above this critical temperature for at least three hours. At the end of the three hour period when I removed the cooking vessel from the styrofoam container, the water was still steaming!

There are many ways that retained heating can be used in developing countries. Retained heating can be combined with solar cooking. Food cooked during the day can be kept warm into the night. Also if during the process of cooking the sky becomes cloudy, the cooking vessel can be transferred to an insulated container and continue cooking. If cooking for a large family, while a dish is cooking in a solar cooker another can be cooking in an insulating container. Also retained heating can be combined with the current use of wood for cooking. The amount of firewood used for cooking would be greatly reduced if food was cooked on the fire only until it reached the boiling point and then transferred to an insulating container. Tests have shown that cooking with fire and a hay-box together, uses one fourth to one third the wood as cooking by fire alone. [20]

The final area I researched was cooking alternatives for when the sun is not shining and solar cookers can not be used. One option I tested was a charcoal reflector oven. It is made out of a cardboard box that has been completely lined with aluminum foil. It has two holes (about 1-cm diameter) towards the bottom of the box, on both sides, to provide the air that is needed for the charcoal to burn. It also has two wires near the top to place a tray of food on. Finally there is a metal pie plate at the bottom, which is meant to hold the burning charcoal. [21]

For my reflector oven tests I heated 6 charcoal briquettes using a chimney starter. I then added one charcoal at a time into the box. I measured the temperature within the box by placing a temperature probe inside it. I then compared the temperature in the box with the number of briquettes inside it. Articles on these ovens have said that each briquette adds 40°F. [21] However, I found that the first briquette adds on average 123 °F/69°C, the second briquette adds 92°F/52°C, the third briquette adds 50 °F/28°C, the fourth briquette adds 36°F/20°C, the fifth briquette adds 30 °F/17°C, and the sixth briquette adds 20 °F/11°C. So as briquettes are added the amount that the temperature increases tends to fall off. The first two briquettes by far contribute the most heat.

I also conducted two other tests to see how well the charcoal reflector oven functions. First, I tested to see how fast it heats up. I placed four charcoal briquettes, which had already been heated for 20 minutes following lighting, into the charcoal oven. I then measured the time it took for the oven to reach its maximum temperature. I found that it took only 10 minutes for the charcoal reflector oven to heat up. The second test I performed was to see how well the charcoal reflector oven maintains its temperature. I conducted my test using four charcoal briquettes. I then measured the decrease in temperature over a three hour time period. I found that the temperature inside the oven decreased by over 100 ° F/60°C after one hour, more then 150°F/90°C after two hours, and over 200 ° F/120°C in three hours. With a blanket on top of the box-oven, the cooling rate would be less.

So reflector ovens heat up quickly, are simply to use, and requires little charcoal to reach high temperatures. It is also efficient when food requires a modest amount of cooking time, about an hour or two. People in developing countries already rely on charcoal for cooking purposes. However, using a charcoal reflector oven will require far less charcoal then using charcoal in the open because there will be less heat loss (especially when the top of the oven is covered with a blanket.

So this summer I have found that an aluminum foil funnel solar cooker, retained heating, and charcoal reflector ovens are all efficient alternative cooking options. These cooking methods can easily be used in developing countries to reduce the use of fire wood and other biomasses, and to improve the lives of the people living in poverty throughout the world.

Acknowledgments

I thank Prof. Steven Jones, the Brigham Young University REU program and the National Science Foundation for the research opportunity this summer at Brigham Young University.

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