Solar Ovens

Joseph L. Waters [1], Beth A. Todd[2]

Abstract – Based on the current consumption of energy and the ever growing population, the world is bound to eventually run out of resources. One major reason is the high rate of consumption and decreasing rate of natural resources. Learning to use renewable resources such as solar power is one way to counteract this deficit. Solar ovens are one of many devices that can be used to capture the sun's energy to heat foods. An activity was developed to stimulate high school chemistry students on the topics of energy, material science and solar power. During this lesson plan, the students will learn the properties behind temperature, the law of conservation of energy and the transfer of energy into food. The students will build a solar oven to test the amount of heat absorbed in different food substances in order to cook them. This paper provides a detailed description of multiple lessons used to successfully build a solar oven and how to use it in practical chemistry applications such as calculating the heat absorbed.

Keywords: energy, the law of conservation of energy, solar power

PURPOSE OF HARVESTING THE SUN'S ENERGY

As part of a National Science Foundation GK-12 project, graduate student fellows at The University of Alabama work in conjunction with science and mathematics teachers from Sumter County schools by presenting their research and developing classroom experiments to aid in instruction of topics. This particular experiment was developed to help an 11th grade chemistry class broaden its knowledge of solar energy and the importance of using renewable energy sources. This experiment was created to expose the classroom to engineering and material science (a mix of chemistry and engineering). This experiment was developed by combining several procedures from different sources in order to create a different type of solar oven. The experiment assisted students in learning concepts on the nature of energy, heat transfer and calculations. In order to save on supplies it would be ideal to have the students in groups. This experiment will take several 50 minute class periods.

Background

One of the most powerful sources of energy in the universe is the sun. Every day for billions of years, massive amounts of solar energy are supplied to the earth [1]. The earth sits approximately 93 million miles from the sun and only captures a small fraction of its solar energy [2]. The majority of this energy comes in the form of visible light [1].Besides biological applications of solar energy, this visible light can be used for heating water, cooking and warming homes. Since solar energy is a clean source of energy, there are no harmful effects to the environment. Several challenges are present for each application when using solar energy. A few main challenges are time dependency, clouds, buildings, pollution and finding a way to effectively harvest and transform the light to energy. The greatest direct challenge when using solar energy for cooking is producing enough heat for cooking [1]. In order to harvest solar energy, a device to capture sunlight or heat is necessary. A few devices that can capture solar light are fluids, solar ovens and solar panels. These devices absorb the light and then convert it into heat [2]. Heat is the transfer or flow of energy due to a difference in temperature between two objects [4]. These devices concentrate large amounts of light through a reflector such as glass, a mirror and plastic lens [2]. Solar ovens use insulation such as aluminum and glass to contain heat or energy from the sun. The rotating plate is a new element added to help evenly distribute the heat throughout the food. The plate helps to keep food that is directly in the sunlight from burning or over cooking. The captured heat is converted into energy to cook the food. Energy exists in two basic

[1] University of Alabama, Box 870202, Tuscaloosa, AL 35487, JLWaters@crumson.ua.edu

[2] University of Alabama, Box 870276, Tuscaloosa, AL 35487, btodd.eng@gmail.com

forms; potential and kinetic [4]. It can be converted from one form to another but it cannot be created or destroyed stated by the law of conservation of energy [4]. The solar oven uses a temperature probe in order to measure the heat which is very similar to a calorimeter. An equation that can be used to calculate the change from heat to energy is

$$Q = C_p \bullet m \bullet \Delta T$$

where Q = heat absorbed or released (in J), C_p = specific heat capacity, m = mass (in g) and ΔT = change in temperature (in °C). It is assumed that no energy is lost to the solar oven or system while cooking is taking place. One way to help your students relate to solar ovens is to describe the mechanics of the oven in relation to a greenhouse [2]. Solar ovens are one of many solar harvesting devices that can help make life simpler and cheaper.

Pre-Activity lesson

To help the students grasp the concepts of solar energy, a pre-activity lesson was developed. This activity introduced the students to the necessary background information in order to completely understand the purpose of harvesting solar energy. The students will read the article "the backgrounder solar heat" and answered several questions to test the knowledge learned. The students/each group should present a project, where they make a poster board about solar energy and heat. This activity can be conducted at home or in the library on the internet. This will ensure that the students have grasped the concepts correctly. Listed below are several sample questions that can be used to test the students understanding of the activity but should not be limited to these specific questions.
(Note: The link for the backgrounder paper http://www.re-energy.ca/docs/solar-heat-bg.pdf)

1. How does the pattern of solar radiation through the day (or year) match the need for air conditioning, heating, cooking, and hot water in your home?
2. How much solar energy comes from scattered light, rather than directly from the sun? What factors affect this?
3. How can you trap the energy from the sun and turn it into something useful, like heat? What factors will affect how high the temperature will go?
4. How is the sun's energy emitted?
5. What are three ways to capture heat from sunlight?
6. What are the limitations when using solar energy?
7. How does a green house relate to a solar oven?

Materials

(*Note: measurements for certain materials are tentative and based on availability*)

The following materials will be needed to construct the rotating plate:

- Scissors
- 2 pointed skewers
- Large cup (plastic or very sturdy)
- 1 small cup (plastic or very sturdy)
- 2 bevel gears
- 2 Paper plates (the stronger the better)
- CD
- Pencils & ruler

The following materials are needed to construct the solar oven

- Two large corrugated cardboard boxes with flaps—one fitting inside the other with about 5 cm between them on all sides and bottom (inner box should be at least 46 x 56 cm)
- A flat piece of cardboard (about 20 cm longer and wider than the larger box)
- A light piece of glass or Plexiglas about 50 x 60 cm
- A thin metal tray, painted black, about 42 x 52 cm (Necessary when not adding the rotating plate structure)
- Aluminum foil
- Water-based glue
- Lots of newspaper
- String (one foot long)
- A stick (Any cross section)
- A rubber band
- One solar panel with motor
- Four zip ties and two pieces of Velcro
- Temperature probe or thermometer

Procedure

Building the Solar oven

1. Lay out all your materials to account for everything.

2. Place some glue on the cardboard and glue the foil to it. In order for the glue to last longer, dilute it with water and apply with a brush. For the smaller box, apply glue to the inside and outside of the box. For the big box just apply glue to the inside only at first. Then apply glue to the inside and outside of the flaps.

3. Cut the Flaps off of the smaller box. Cut the flaps into small squares (roughly 4cm) that are stacked and glued together as shown in Figure 1. Create a minimum of four. Glue the small columns to the bottom of the big box. These small columns will help support the little box.

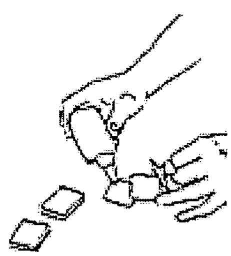

Figure 1. Gluing the small squares together

4. Take the pieces of newspaper and cut them in half. Then crumble the news paper in small balls (about the size of an orange or lemon). Place the crumbled pieces into the bigger box, enough to cover the bottom.

5. Insert the little box into the bigger one so that it is stable. Place pieces of news paper on the side for extra insulation. (Refer to Figure 2)

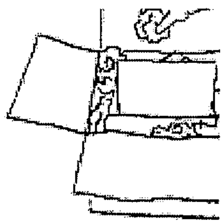

Figure 2. Place insulation in large box

6. Cut the flaps of the larger box so that they cover the insulation once folded over.

Glue the overlap of the cut flaps to each other. (Refer to Figure 3)

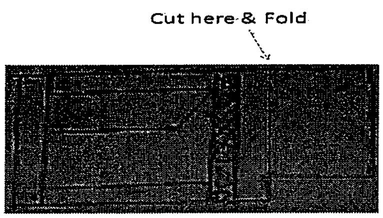

Figure 3. Cutting the edges and folding them over

Making the Lid

7. Obtain a flat piece of cardboard. Place the piece of cardboard in the center of the box. Mark where the sides of the box end in order to be able to fold the flat piece of card board over.

8. Make creases in the flat piece of card to simulate the sides of the top. Make two parallel horizontal cuts at the top and at the bottom so that it can bend, four cuts total. (Refer to Figure 4)

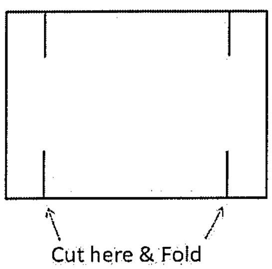

Figure 4. Making the Solar oven top

9. Glue a layer of aluminum foil to the bottom of the flat card board piece. Fold the cuts over and glue them to the top to stabilize the top (do not glue the top to the main oven). Make sure the top fits tightly in order to ensure optimal cooking. (Refer to Figure 5)

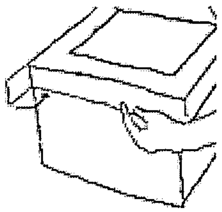

Figure 5. Fitting the Solar Over top to the base of the solar over

10. The next step is to make a hole for the sunlight to enter into the oven. Draw a rectangle on the top side, in the center of the card board resembling the piece of glass. Use a ruler for accuracy. Your rectangle should be slightly smaller than the glass (at least 0.5 inches)

11. Cut the sides and the bottom of the rectangle. Turn the lid over and glue the piece of glass to the inside of the lid. Press on glass until the glue is completely dry. (Refer to Figure 6) (PLASTIC WRAP FOR SUBSTITUTE)

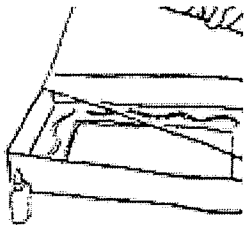

Figure 6. Carefully place your Plexiglas in the center of your top

12. Chose a ideal place for the thermometer. Make a hole in the top and place the thermometer inside. Make sure you are able to read the numbers.

13. Obtain a stick and some string. Tie the piece of string around the stick so that it is secure. Bend up the rectangle and puncture two holes on each side. Slide the string through the holes. The stick will be used to prop up the top for sunlight to enter, use the string to adjust the height of the opening. Use two sticks if it is windy outside.

Making the rotating plate

1. Lay out your materials and make sure you have all the necessary pieces. Start by putting a ring of glue on the rim of the smaller cup. Place the larger cup inside the small cup; be sure to press down until the glue dries.

2. Take the CD and glue it directly in the middle on top of the smaller cup. Place the glue around the edge of the cup. Wait until glue dries before continuing. (Refer to Figure 7)

Figure 7. The cup and CD apparatus

3. Using a measuring tape or ruler, measure .5 inches from the top of the smaller cup and mark with a marker. Pierce the marked spot with a skewer. Slide the skewer evenly in the cup and pierce the other side of the cup. Make sure both holes are level to ensure stable rotation. Remove the skewer from the cup.

4. Take the skewer and glue one of the bevel gears to it. The gear should be glued to the flat top of the skewer with the gears teeth facing the flat end. Glue the gear as close as possible to the flat edge of the skewer. (Refer to Figure 8)

Figure 8. The first bevel gear and skewer

5. Take this skewer and pierce the bottom of the cup in the middle of both cups. Pull the skewer all the way through so that the bevel gear is at the bottom of the larger cup.

6. Now it is time to make the other skewer and bevel gear. From the pointed end of the skewer, measure ~2 ¼ " and mark it. This is where you will glue the bevel gear. Glue the gear so that flat part of the gear is at the marked line on the skewer and facing the sharp end. Allow glue to dry before moving on. (Refer to Figure 9)

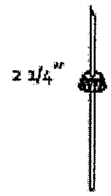

Figure 9. The second bevel gear and skewer

7. Insert your cups into the small box. Make a hole in the side of the small and larger box for the skewer. Make sure the hole in the larger box aligns with the small box. The hole for the skewer should not be too big. If the hole is too big, heat will escape. Puncture the holes for both boxes with the skewer, so that it comes out the side of the box. Try to be as precise as possible. Remove the cups and skewers to finish building the rotating device. (Refer to Figure 10)

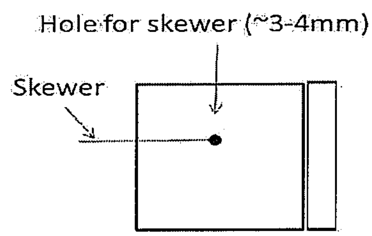

Figure 10. Position on where to puncture the larger box

8. Insert the skewer into one of the holes on the side of the large cup. You will probably have to angle the skewer to get the sharp end in. Once the skewer is completely in, slide the sharp end of the skewer into the other hole (you may need to squeeze the cup to achieve this, but do so gently). (Refer to Figure 11)

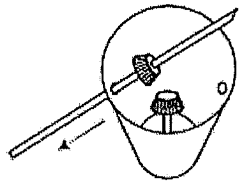

Figure 11. Sliding the second skewer into the cup

9. Once both skewers are in, gently push the horizontal skewer in until the gears touch and the teeth are engaged. Verify this by looking in the cup and making sure the gear teeth are interlocked. (Refer to Figure 12)

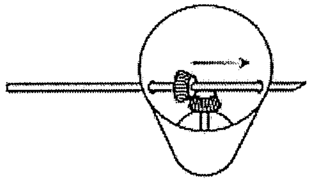

Figure 12. Positioning the second skewer to interlock the gears

10. Take your plate and mark the center with a pencil. Puncture the middle of the plate with the top of the vertical skewer and slide the plate down so that it rests on top of the CD.
11. Glue the plate to the skewer (Do Not glue the plate to the CD!!). Allow the glue to dry. (Use the extra plate as a contact for the food surface that can be interchanged just in case food is spilled on it)
12. Once all glue is dry, make sure the gear are interlocked and twist on the horizontal skewer and watch the plate rotate.
13. Place the completed rotating plate into the solar. Carefully slide the skewer out the side holes made earlier.
14. Take the top of the solar over and place the motor on top. Make sure the motor aligns with the skewer. Remove the motor and make four holes for the zip ties. Tie the motor down so that it is secure.
15. Connect the solar panel and the motor. Place a piece on the back of the motor and on the solar oven top.
16. Place your rubber band around the skewer first and then around the motor. (Note: Do not take the top off the solar oven without removing the rubber band!)

Guidelines for Cooking

- It would be ideal to place food into a pot with a lid but not necessary.
- Make sure to orient the box to face where the sun will be in the late morning to avoid having to move the box.
- Make sure lid is oriented to reflect the most sunlight into the box.
- The food will cook better when it's sunny and warm outside. Try not to cook on a windy day.
- Do not stir the food while it's cooking. Temperatures inside the box can reach up to 275° F and lifting the lid will allow for heat to escape.
- The shadow of the cooker should be directly behind the box.
- One to two hours for rice, fruit, above-ground vegetables, pretzels.

- Three to four hours for potatoes, root vegetables, some beans (including lentils) and most bread
- Five to eight hours for most dried beans.

Data Table

Food Item	Specific Heat, C_p (Joules/g°C)	Mass, m (grams)	Final Temp, T_2 (°C)	Initial Temp, T_1 (°C)	Calculated Heat, Q (kJ)

- For a list of specific heats for foods visit: http://www.engineeringtoolbox.com/specific-heat-capacity-food-d_295.html
- There are no constraints for foods. The table data is limited to four spaces for the convenience of space in this paper but it is encouraged to try several different foods to give a broader spectrum to the students.

Post-Activity lesson

During the session following the activity, students may discuss the following questions.

1. What is the purpose of insulation in the solar oven?
2. Calculate the percent difference of the mass of the food using the formula Mass % lost = $\frac{Final\ mass - Initial\ mass}{Initial\ Mass} \times 100$
3. Construct a plot of Heat vs. Mass %
4. Compare your results from question three with your classmates and compose a scientific conclusion.

Conclusion

Student Enthusiasm- This module will be used in a high school chemistry classroom in the beginning of the spring semester when the weather permits, for validation of the best results with the solar panel and heating of the oven.

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation under GK-12 Grant No. 0742504.

REFERENCES

[1] Greenlearning.ca, "Building Your Own Solar Oven," accessed October 2012.
[2] Greenlearning.ca, "Backgrounder Solar Heat," accessed October 2012.

[3] U.S. Dept. of Energy, "What Does the Sun Give Us? (Five Activities)," Office of Energy Efficiency and Renewable Energy, pp. 19-30.
[4] L. Dingrando, K.V. Gregg, N. Hainen, P. Lampe, C. Roepcke, C. Wistrom, "Energy and chemical change" Chemistry Matter and Change, pp. 488-497, 2002
[5] U.S. Dept. of Energy, "'Nano'tubes Surface Area and NanoSolar Cells," Office of Energy Efficiency and Renewable Energy.
[6] The NEED Project, "Solar," Secondary Energy Infobook, www.NEED.org, pp. 40-43.
[7] U.S. Dept. of Energy, "Build a Pizza Box Solar Oven," Office of Energy Efficiency and Renewable Energy, April 2006.
[8] Union of Concerned Scientists, "Renewables are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms," Project Coordinator: R. Sherman, 2003.

Joseph L. Waters

Joseph Waters is currently a doctoral student in Metallurgical and Materials Engineering at the University of Alabama. He is originally from Yonkers, New York. He has a B.S. in Chemistry from Virginia State University. He is interested in using chemistry to create a more efficient dye sensitized solar cell. Joseph truly has a passion for helping others and using science to make the world a better place for future generations.

Beth Todd

Dr. Beth Todd is an Associate Professor in the Department of Mechanical Engineering at the University of Alabama. She currently holds the position of principal investigator for the University of Alabama's NSF GK-12 program. Dr. Todd received her undergraduate degree in Engineering Science from Pennsylvania State University, a master's degree in Applied Mechanics and a Ph.D. in Mechanical & Aerospace Engineering from the University of Virginia. Currently Dr. Todd is researching the design and analysis of devices in the application of assistive technology in the human body.