# Xu Solar Furnace For Recycled Plastic Lumbers

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**Abstract:** Xavier University- Ateneo de Cagayan is one of the top universities in Mindanao and is located in Cagayan de Oro City. The campus has a cafeteria that offers many food outlets and serves the students and the campus community every day. Almost all people in the campus go to the cafeteria and consume different products contained in plastic materials and one of these plastic materials is HDPE plastic (High Density PolyEthylene). However, the amount of HDPE plastic in Materials Recovery Facility gradually increases, approximately 66% increase from 2014 to 2015.The study aims to recycle the product into a plastic lumbers using solar furnace. The design of the solar furnace is by utilizing parabolic solar reflector with an addition of Fresnel lens. There are two types of Fresnel lens being used, spot lens and linear lens. One of the main goals of this study is to generate a melting temperature using parabolic mirror, parabolic mirror with spot lens, and with linear lens. Once the HDPE plastic is melted using the solar furnace, the molten plastic would be molded into plastic lumbers. Results showed that the highest temperature obtained using parabolic mirror with linear lens and spot lens is 193℃ and 240℃, respectively, which is greater than the required melting temperature of the HDPE plastic of 130℃. Based on the results, the designed XU Solar Furnace has the ability to melt the HDPE plastic materials and recycle it into plastic lumbers.

**Index Terms**: HDPE plastic, parabolic solar reflector, plastic lumber, solar furnace, recycle.

## 1. INTRODUCTION

The most common plastic waste that can be found in XU campus is the HDPE or high density polyethylene. It has a wide variety of applications such as shampoo containers, toys, piping, bottle caps, and other products that has a number "2" identification code in it in which indicates that it is HDPE type of plastic. HDPE is polyethylene thermoplastic made of petroleum. A thermoplastic is one of the main types of plastic and has a melting point of 130°C or 266°F which can be softened by heat and can be molded into different forms. HDPE contributes one third of the world's plastic waste in 2010 and the amount of HDPE in XU campus increases as students consume most of the products that utilizes HDPE as food containers every day. This study focuses in the application of recycling plastics (HDPE) in XU campus to produce a plastic lumber. It involves processes such as shredding of HPDE into tiny pieces and melting it by heating. By shredding it to small pieces, it easier to heat and melt the plastic materials. The purpose of heat addition is to melt the plastic at given amount of temperature for it to undergo the molding process and to form the plastic lumber. The type of heat addition process applied in this study is solar heating which utilizes a solar heater that focuses the solar thermal energy into the solar furnace. The solar energy is renewable and it is not harmful to the people. With the idea of melting the plastic and turning it into a new product, which is plastic lumber, then it can be used as an alternative material for wooden lumber, concrete walls, and may be useful in construction of building. More importantly, not only it helps to minimize plastic waste in the XU campus, but also by producing an output in the recycled plastic that has many purposes that can be both beneficial to the XU campus and the nearby communities.

### 1.1 Statement of the Problem

There are many plastic waste materials in the XU campus and it is available mostly in the cafeteria, garbage bins, and waste facilities in the campus. Usually the plastic waste materials found inside the campus is a HDPE type, in which, it is hard to dispose due to its long life span, it takes many years to decay and also contributes a big part of plastic waste in the world. The problem is that the quantity of plastic (HDPE) in the XU campus increases every day.

### 1.2 General Objective

To recycle HDPE in the XU campus by melting.

### 1.3 Specific Objectives

(1) To design and fabricate shredder and solar furnace.
(2) To mold the molten plastic into 50 mm x 70 mm x 150 mm plastic lumber.
(3) To measure the compressive strength of the plastic lumber.

### 1.4 Statement of the Hypothesis

$H_o$. The fabricated solar furnace must be able to supply a \temperature more than 130°C.
$H_a$. The fabricated solar furnace must be able to supply a temperature below 130°C.

### 1.5 Significance of the Study

The significance of this study is to reduce the quantity of HDPE in the XU campus by recycling it and by moulding plastic lumbers that becomes an alternative material for wood, concrete, bricks and other for other purposes. The use of plastic lumber will decrease the dependency of wood for construction of houses, making furniture, etc. and minimize the quantity of HDPE in the campus. Using solar furnace is a free and renewable source of energy, which comes from the sun and does not pollute the environment, and also saves energy consumption. The most important objective of the study is to support and contribute a healthy environment for the XU campus.

### 1.6 Scope and Limitations of the Study

The scope of the study is the XU campus where HDPE waste plastic materials are abundant. The location is the school campus in which HDPE is mostly found and serve as a source of raw materials (HDPE) in this study. The raw materials are gathered in the school campus, and this will serve as a basis of the study and data gathering. Design, fabrication and testing of solar furnace take place in the XU campus only. The study excludes other heat source other than sun, such as gas that can produce flame, in which not suitable for the study. Only HDPE type plastic material will be used as specimen because other plastic materials have different composition and properties, such as melting point, specific gravity or density which may vary in collecting data in melting temperature. Increasing the output product (plastic lumber) per day is not covered in the study.

### 1.7 Theoretical Framework

This study applies the approach of quantitative method of research. This study aims to provide a design and calculation of the required parameters. One of the important processes in this study is the plastic materials shredded into small pieces in a given amount of time and the design of the solar furnace which indicates the possible outcome of the process. The design of the solar furnace is geared toward the increase of efficiency or performance in collecting the thermal energy from the sun, converting light to heat and trapping the heat in the solar furnace. The researchers will identify and record the temperatures at a given amount of time through adapting the concentration of sunlight in the solar furnace which has the capability of melting the plastic materials. The amount of heat to be applied in the plastic materials is one of the major factors to be measured well. The compressive strength of the output or the plastic lumber is measured through universal testing machine (UTM) in the XU engineering laboratory. The accuracy of measurement in each variable that must be measured is very critical throughout this study. The research flow diagram is shown in figure 1.

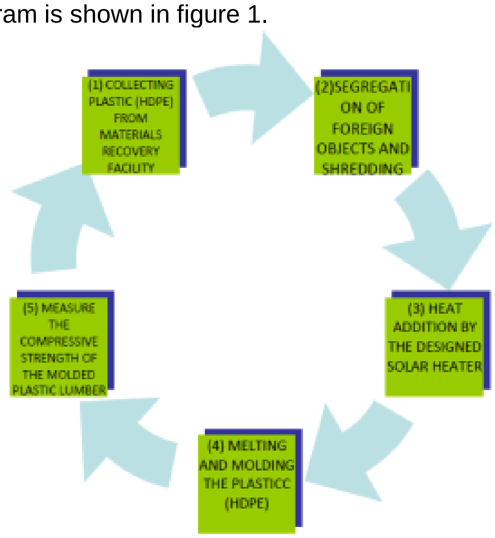


***Figure 1**. Research Flow Diagram*

## II. LITERATURE REVIEW

One of the topics of our study is “Solar heating”. Solar heating is a heating process which uses a system of heating that converts solar energy into heat. The following studies may support and explain how relevant solar heating in our study. In the article of the International light and light-based technologies written by the Australian Engineers, entitled, “Cooking with the sun” it was being discussed that the invention of the solar oven or solar cooker brought a great impact to the lives of humanity and to the prevention of pollution. Solar cooker is a device used for cooking and is powered by the heat coming from the sun. The said device converts sunlight into heat. According to the article written by the Australian Engineers, using solar cooker has many advantages. One of these advantages is it is inexpensive to make. It does not produce gases or other forms of pollution, and it prevent the hazardous effect of smoke production The study of Jennifer entitled “Why cook with the sun?” supports the above study of the International light and light-based technologies written by the Australian Engineers about the importance and advantages of using solar cooker. According to her study, the use of solar cooker has a great contribution in preventing and avoiding global warming and deforestation. The utilization of the rays of the sun to cook food, the use of firewood is minimized. Thus, upon using the solar cookers of different types, the cost of using gas and electricity is not needed anymore. Another article about solar cooker is written by Quannene M. et. Al. (2009) in their study, entitled, “Design and realization of a parabolic solar cooker”. Like the above study, they also mentioned how useful solar energy is. According to them, sun’s energy is not only used to make energy but it is also used to cook. They also discussed the difference between a box type and a parabolic type solar cooker. In the discussion they mentioned that a box type solar cooker works on the principle of trapping the sunlight and transforming it into heat when it is absorbed by the pot. On the other hand, a parabolic type of solar cooker works on the principle of concentrating the rays of the sun into single point. The larger the parabolic solar cooker, the more powerful it is. They also said that the cooking temperature begins at 65$^{o}$C. In the study of Wierckx N. et al., entitled “Plastic waste as a novel substrate for industrial biotechnology” they claimed that, in 2010 alone, two hundred and seventy-five million tons(275MT) of plastic were produced. If these numbers of plastic materials are not recycled, it may cause a great environmental problem. The wide spread of plastic waste materials also contributes to the large-scale pollution of the oceans such as, “The Great Pacific Garbage Patch” and “The Trash Vortex”. That’s why in the study of Wierckx N. et al. plastic recycling is greatly recommended. For instance, in their study, they mentioned that in the beverage industry, Poly ethylene terephthalate (PET) has contributed significantly to reducing energy expenditure during transportation. PET can be recycled also easily. Another type of plastic that can be very useful if recycled is Polyurethane. Polyurethane is a type of plastic that is used to make clear liquid which hardens any surface it touches. It is very useful in a wide range application including construction, transportation, furniture, and medicine. So, the study of Wierckx N. et al simply says that recycling plastic is very important because, besides of minimizing its hazardous effects, it has also many uses. On the other hand, the study of Miller L. (2014) et al., entitled “Challenges and alternatives to plastics recycling in the automotive sector” clarifies that nowadays plastics are widely used in making products, especially in the automotive sector, because they are lightweight, moldable, and perceived to be highly recyclable materials. If plastics are used in automobiles the weight of vehicles will be lowered. Then, if the weight of the vehicle is lowered its efficiency will increase. The study of Miller L. (2014) et al. only reminds us one of the uses of plastics.

## III. RESEARCH METHODOLOGY

### 3.1 Research Process Flow

Recycling HDPE plastics is composed of three major processes which includes; shredding, heat addition and molding, as shown in figure 2. In doing so, the flow of processes is given consideration which enables the output product to be easily adjusted for the collection of data.

Shredding Heating Molding

***Figure 2.*** *Recycling HDPE Process*

The shredding process utilizes simple shredding equipment like a pair of scissors, blender or a small shredder machine in order to turn HDPE plastic materials into small pieces. The shredder machine is a small fabricated two-shaft shredder powered by a 300 Watts electric motor. The shredder has 6 round blades with about 60 mm in diameter. The design of the shredder is a scaled down shredder machine which can handled any type of material to shred. At the bottom of the shredder is a container which catches the shredded HDPE. The second process is heat addition which is powered by solar energy through concentrating the solar heat into a solar furnace. Solar furnace is designed for collecting the concentrated heat from the sun and to meet the melting point of the HPDE plastics which is 130ºC or 266 ºF. The solar heater can increase the solar heat from the sun and diverting its heat to the designed solar furnace. The molding process is designed to hold molds of the desired figure of the recycled plastics. The molder is attached directly to the solar furnace. The molder has two parts, the molding container and a top cover with mold detail. The molding process is simultaneous with the heat addition process. The plastic materials are placed first into the holes of the molder then let it melt. Then fill the remaining half of the mold with plastic then let it melt. Same process is done until the melted plastic reached the black area of the molder.Finally, place the top cover of the mold into the molder container and press the top cover to completely form the melted plastic. The preliminary design of the molder is a rectangular in shape for it can be process for any useful plastic products such as plastic lumber.

### 3.2 Description of Equipment and Materials used

The equipment and materials used in this study are the HDPE plastic materials, plastic shredder, solar heater, solar furnace and a molder. The HDPE are plastic material that are commonly used domestically and can become a waste product after using. Xavier University campus is a good source of HDPE, where most of its population are using this kind of plastic. HDPE plastic is identified by its number 2 print on the bottom of the container based from resin identification code, as shown in Figure 3. Mostly the bottle caps of a bottled beverage drinks are made up of HDPE, specifically mineral water, soft drinks and etc.


***Figure 3****. Identification Code of HDPE*

This kind of plastic material has a property of a thermoplastic which can change in shape when heated and can be molded into different forms. The melting temperature of HDPE is 130°C and has a higher resistance of burning compared to other plastics. Theoretical compressive strength of this plastic is 31.7 MPa, thus these plastic materials are good alternative materials in construction and other fabrication and structures.The plastic shredder as shown in figure 4 is the tool used for cutting the plastic into small pieces. The HDPE materials need to be turned into tiny bits so that it can be molten and be molded easily. The designed shredder of the study is a high speed shredder inspired by the concept of a food blender and a general purpose shredder. The blender is a kitchen and laboratory appliance that can tear off food and other substances.

***Figure 4****. General Purpose Shredder*

***Figure 5****. Blender*

The blender as shown in figure 5 has sharp rotating blades on its bottom which can be used to shred the plastic. The general purpose shredder is a machine used to cut any material that is initially solid into small bits of plastic materials. The general purpose shredder has a rotating shaft and a circular disk with cutting edges. The general purpose shredder is a large machine which is an expensive machine element and it takes a long time to fabricate. The designed plastic shredder as shown in figure 6 in this study is a combination of the general purpose shredder and a high speed cutting concept of the blender. The plastic shredder is a miniature general purpose shredder which has two rotating shaft with a circular disk and with cutting edge. The high speed motor of the blender used to supply power to the plastic shredder.

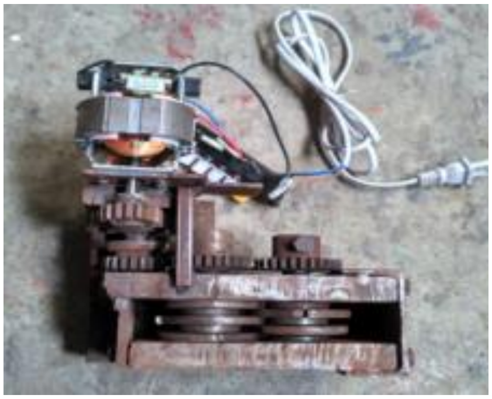

***Figure 6**. Designed and Fabricated Shredder*

The rotating cutting disk of the shredder as shown in figure 7 is made up of metal plate formed into a disk with a cutting edge. Strengthen the cutting edge of the disk is aided with a tool bit tip is placed on it to secure its sharpness maintain in high speed shredding. Cutting disk of the shredder are put it a shaft with a spacer plate in between to complete the shredding concept of the general purpose shredder.

***Figure 7.** Cutting disk of the plastic shredder*

The solar furnace is designed with different solar concentrator, namely parabolic reflector and two types of Fresnel lens. In this study, solar furnace is the main component and is used to melt the HDPE materials. The most crucial part in this study is the designing of the solar heater which can achieve more than 130°C. There are many design of solar heater or concentrator but only few designs can achieve a good amount of temperature in a short duration of time. Solar heaters have a metallic parabolic reflector made out of stainless reflector sheet. The parabolic reflector as shown in figure 8 must have a good reflective surface because it has to collect and project more light energy from the sun. The diameter of the parabolic reflector is around 105 cm and a depth of 30 cm to get focal length around 22.97 cm.

***Figure 8**. Parabolic Mirror/Reflector*

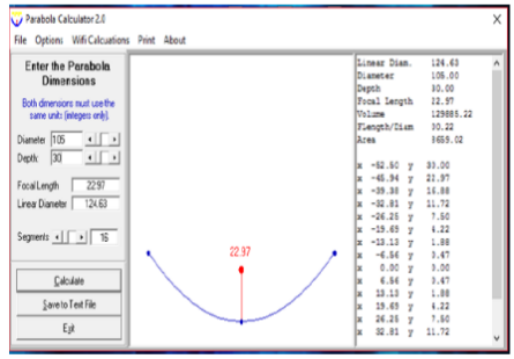


***Figure 9**. Parabolic Calculator*

The focal point of the parabolic mirror varies on its depth. In order to get the focal length of the parabolic mirror, the use of a parabola calculator software easily solves the focal by just a given diameter and depth as shown in figure 9. The researchers design the diameter and depth and adjusting it to get the desired focal length. The final diameter is 105 cm and a depth of 30 cm to get focal length around 22.97 cm.

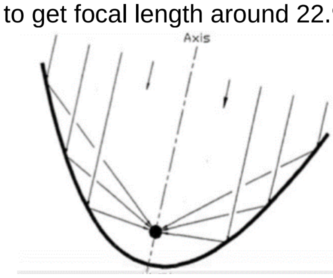


***Figure 10**. Parabolic Reflection Concept*

The concept of a parabolic reflector or dish is to concentrate sunlight to a single point or a line as shown in figure 10. The reflector is axially symmetrical and shaped so that its cross-section is a parabola that has a property of bringing parallel rays of light from the sun and eventually generates high temperatures quickly to focal point. Another type of solar concentrator used in the solar heater design is the Fresnel lens. The Fresnel lens is a compact lens used in lighthouses, head lamps, projection TV and some other imaging purposes. This type of lens is capable of reducing the amount of material required compared to a conventional lens by dividing the lens into a set of concentric annular sections. An ideal Fresnel lens would have infinitely many such sections. In each section, the overall thickness is decreased compared to an equivalent simple lens. This effectively divides the continuous surface of a standard lens into a set of surfaces of the same curvature, with stepwise discontinuities between them. Fresnel lens is often used in magnifying light but also, in the process of heating. It is in reverse position in which it focuses the light into a point where it concentrates the solar energy coming from the sun and produces heat. The Fresnel lens has a series of concentric grooves in its surface. As a result, while a having a narrow profile, is capable of focusing light similar to a conventional optical lens but has several advantages over its thicker part as shown in Figure 11.

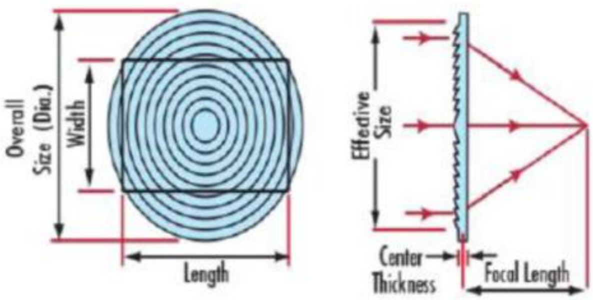


***Figure 11.*** *Concept of Fresnel Lens*

***Figure 12****. Linear (left) and Spot (right) Fresnel Lens.*

There are many kinds of Fresnel lenses and these lenses have two types: linear and spot lens. The difference of these two is that spot lens concentrates more energy in a single point which is called "spot" and generates very high temperature in it as shown in figure 12. On the other hand, linear lens produces a spot but not as small compared to spot lens, although it concentrates solar energy to its point but not likely to generate much higher temperature. The linear lens used in this study came from a rear end projection TV. This type of Fresnel lens is not easily available in the market, especially here in the Philippines. This study utilizes linear and spot lenses which should be used for melting the HDPE. The solar furnace is a tight box made of aluminium material, having light weight property and high thermal conductivity of 205W/m-K. The molder is also made like a collapsible rectangular box and has two small cylindrical holes at the top. Since the molder is a box in shape, the molten plastic would occupy the molder at the bottom and the excess molten plastic will protrude into the two small cylindrical holes at the top, as shown in figure 13. As the plastic starts to melt, a flat sheet is used to scrape and press down the molten plastic and eventually form the molten plastic into a perspective of a lego. This moulder design is the final product of the molten plastic (HDPE).

***Figure 13.*** *Solar Furnace Molder*

### 3.3 Data Collection Procedure

The researchers obtained the information about the Solid Waste Monthly Report of the Materials Recovery Facility (MRF) directly from the Physical Plant Office (PPO). Comparing the amount of kilogram per year indicates if there is decrease or increase of plastic waste generation in the campus. After collecting data of the solid waste, the researchers gathered plastic samples of HDPE plastics from Materials Recovery Facility, usually bottle caps to be used as a specimen for the experiment. The gathered plastic materials are to be weigh for the exact amount of plastic to be shredded corresponding to the required volume of the plastic lumber. The testing area of the solar heater is located in Xavier University Soccer Field which is an open field and ideal for gathering maximum solar thermal energy. The experiment composed of three parts, using parabolic mirror, parabolic mirror and (spot) fresnel lens and (linear) fresnel lens. The testing starts from 9:00 AM and ends on 3:00 PM depending on the clearness of the sky. Each part has the same parameters to be obtained, the amount of plastic in the container in kg, ambient temperature, time of heating the container in a day, recording the temperatures outside of the container in every specific time, and the temperature of the plastic inside the container. The temperature of the plastic in the container is to be measured and observed as its start to melt. When the HDPE plastic is melted, it is an indication to start molding it directly inside the solar furnace through manual compression. After molding its desired form and removing the heat, the product is ready to be tested in the universal testing machine (UTM) in the Materials Engineering laboratory. The researchers will then test its compressive strength and comparing it to an ordinary concrete brick. The gathered data is then the primary source of the study.

## IV. RESULTS AND DISCUSSION

### 4.1 Presentation of Data

The study focuses on recycling HDPE plastics by melting it using solar heating to form a useful product out of these plastic waste materials. The researchers then designed a solar heater which will magnify the normal heat that the sun produced to obtain a greater amount of heat. The designed solar heater has 3 main heat magnifying components: Parabolic Reflector, Linear Fresnel Lens, and Spot Fresnel Lens. These 3 components have the same and main concept of concentrating the solar heat into a specified container to produce a higher temperature capable of melting HDPE plastics. To increase the melting ability of HDPE plastic the researchers also designed a shredder which is used in shredding the plastics and turning them into small pieces. Data collection focuses on the testing of the solar furnace. Sample Data Types of HDPE Plastic inside Xavier University Campus are (1) Bottle Caps, and (2) Food containers The amount of HDPE to form a plastic lumber:

Mass = 510 g

Volume = 525 cm$^3$

| YEAR | VALUE | unit |
|---|---|---|
| 2014 | 1197 | kg |
| 2015 | 1809 | kg |
| total | 3006 | kg |

***Table 1****. Xavier University Solid Waste Annual Report of Plastic Collected for the Year 2014-2015*

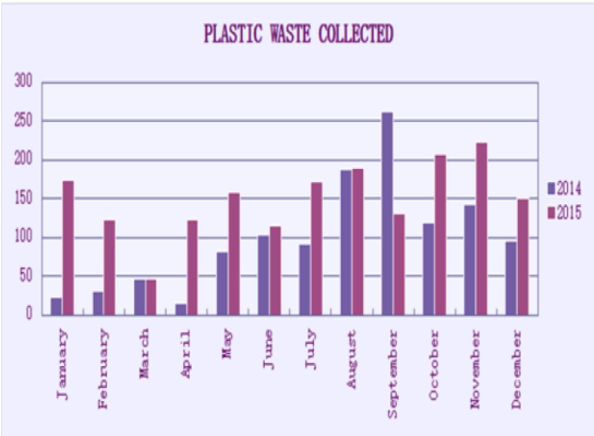


***Figure 14.*** *Graphical Representation of the*

Collected Plastic Waste Monthly Report (2014-2015)

Solar Heating

A. The Parabolic Mirror (Closed Container) Test Results

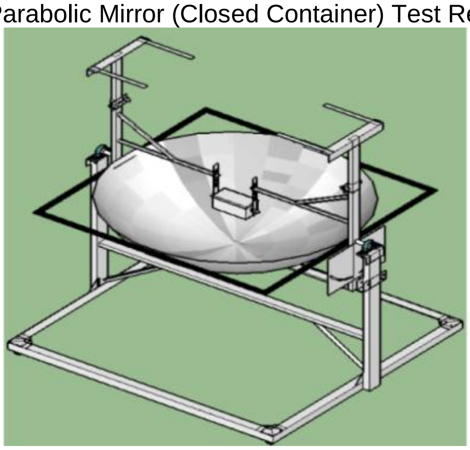

***Figure 15.*** *Parabolic mirror (closed container)*

The researchers tested first the solar furnace using only the parabolic mirror as the heat concentrator. The data was collected from 10:00 AM to 11:00 AM with 5 minutes interval. It was conducted at Xavier University Soccer Field.

| Time of the day | Ambient temperature °C | Temperature reading °C | Mass of HDPE (g) | Volume (cm^3) |
|---|---|---|---|---|
| 10:00 – 10:10am | 31.7 | 45 | 510 | 525 |
| 10:10 - 10:15 am | 30.2 | 55 | 510 | 525 |
| 10:15 - 10:20 am | 31.8 | 63.8 | 510 | 525 |
| 10:20 - 10 25 am | 31.6 | 60 | 510 | 525 |
| 10:25 - 10:30 am | 31.9 | 40 | 510 | 525 |
| 10:30 - 10:35 am | 32.6 | 41 | 510 | 525 |

**Table 2.** Data gathered from the 1st experiment using parabolic Mirror (closed container)

Analysis:

The first testing of the designed solar furnace was conducted at Xavier University Soccer Field. Based on the results and data gathered, the researchers found out that the designed solar furnace is not effective when the source of heat is the parabolic mirror only. The highest temperature that the parabolic mirror can produce is 63.8 °C which is very small compared to the required plastic melting temperature of 130 °C. It was also observed that the main factor affecting the effectiveness of the solar furnace was the weather. B. The Parabolic Mirror with Spot Fresnel lens Test Results The researchers then tested the solar furnace with different set-up. Set-up 2 is the parabolic mirror with the addition of the Spot Fresnel Lens. This was done at Xavier University Soccer Field with the same time as the first set-up, from 10:00AM to 11:00AM, and same time intervals.


***Figure 16****. Parabolic Reflector and Spot Fresnel lens* (Open Container) Heating Sample Result

| Time of the day | Ambient temperature °C | Temperature reading °C | Mass of HDPE (g) | Volume (cm^3) |
|---|---|---|---|---|
| 10:35 – 10:40am | 31.8 | 130 | 510 | 525 |
| 10:45 - 10:50 am | 31.6 | 240.6 | 510 | 525 |
| 10:55 - 11:00 am | 31.9 | 235.0 | 510 | 525 |
| 11:00 - 11:05 am | 32.6 | 180 | 510 | 525 |
| 11:05 - 11:10 am | 32.3 | 85 | 510 | 525 |
| 11:15 - 11:20 am | 32.0 | 60 | 510 | 525 |

***Table 3****. Data gathered from the 2nd experiment using parabolic Mirror with Spot Fresnel Lens(open container)*

Analysis: As for the previous result, the required temperature will never be achieved upon relying merely on parabolic mirror. Considering all the observations, it was decided to use Fresnel Lens for the purpose of increasing the heat that the designed solar furnace can achieved. Fresnel Lens magnifies the heat energy coming from the sun. For this particular reason, the designed solar furnace, with the addition of Spot Lens, produced a much greater temperature needed. Based from the results, the solar furnace temperature reaches at the highest equal to 240.6 °C, a preferred temperature for melting plastic.C. The Parabolic Mirror with Spot Fresnel lens (Closed) Test Results On the third test, because the study depends on the heat coming from the sun, the researchers decided to conduct the test as long as the sun comes out, which is at 9:30 AM on that day, and ended the data collection as the weather changes from sunny day to cloudy day, which happened at 10:00 AM. The testing was still conducted in Xavier University Soccer Field.

***Figure 17.*** *Parabolic Reflector and Spot Fresnel lens* (Closed Container) Heating

| Time of the day | Ambient temperature °C | Temperature reading °C | T of parabolic reflector °C | Temp. of HDPE °C | Volume (cm^3) |
|---|---|---|---|---|---|
| 9:30 - 9:35 am | 31.6 | 162 | 74.3 | 28.4 | 510 |
| 9:35 – 9:40 am | 31.7 | 240.6 | 70.2 | 38.5 | 510 |
| 9:40 – 9:45 am | 31.7 | 237.7 | 68.1 | 54.4 | 510 |
| 9:45 – 9:50 am | 32 | 202.8 | 69.8 | 57.0 | 510 |
| 9:50 -9:55 am | 31.8 | 190.5 | 68.7 | 56.2 | 510 |
| 9:55 – 10:00 am | 32.6 | 187.1 | 67.3 | 54.2 | 510 |

**Table 4.** Data gathered from the 3rd experiment using parabolic Mirror with Spot Fresnel Lens (closed container)

Analysis: the third test, same set-up with that of the second test was conducted. The use of the Spot Fresnel Lens was added to the designed solar furnace. However, the weather is different prior to the weather of Test 2. Most of the time of the day, the sky is cloudy. Clear sky lasted only for 30 minutes, from 9:30 AM to 10:00 AM. Given that situation, it is expected that the achieved temperature was smaller compared to the previous test. As the results shown, Table 4, the highest temperature achieved by the solar heater in Test 3 was 202.8 °C which was 37.8 °C lower than that of the highest temperature reached in Test 2. D. The Linear Fresnel Lens Test Results The researchers final testing was done using Linear Fresnel Lens as the concentrator of solar energy. The testing started at 11:00 AM and ended at 1:00 PM with 5 minutes interval. The test was still conducted at Xavier University Soccer field.

***Figure 18****. Linear Fresnel Lens Open Container Heating*

| Time of the day | Ambient temperature °C | Temperature reading °C | Mass of HDPE (g) | Volume (cm^3) |
|---|---|---|---|---|
| 11:00 -11:10 am | 29 | 166.8 | 510 | 525 |
| 11:10 -11:20 am | 29 | 169.1 | 510 | 525 |
| 10:30 - 11:40 am | 30 | 193.2 | 510 | 525 |
| 11:40 – 11:50 am | 30.8 | 192.2 | 510 | 525 |
| 11:50 – 12:00pm | 30.0 | 171.1 | 510 | 525 |
| 12:00 – 12:10pm | 30.3 | 192.2 | 510 | 525 |
| 12:10 -12:20 pm | 30.7 | 186.3 | 510 | 525 |
| 12:20 – 12:30pm | 30.1 | 184.2 | 510 | 525 |
| 12:30 – 12:40pm | 30.1 | 164.9 | 510 | 525 |
| 12:40 – 12:50pm | 30.6 | 158.6 | 510 | 525 |
| 12:50 – 1:00 pm | 30.9 | 100.3 | 510 | 525 |

**Table 5**. Data gathered data from the 4th experiment using Linear Fresnel Lens (open container)

Analysis: To complete the testing process and data gathering, the researchers conducted the final set-up of the designed solar furnace at the same place as that of the other tests which was in Xavier University Soccer field. The last set-up involved the use of Linear Lens as the main and only concentrator of light energy. Same as the Spot Lens, Linear Fresnel Lens magnifies also the heat coming from the sun to produce a much greater amount of heat needed to melt HDPE plastics. Nevertheless, Linear Fresnel Lens produced a wider and more spread light than that of the Spot Fresnel Lens which magnifies the light of the sun to produce a spot of light with a higher temperature. So, for that reason it is clear that the heat produced by the spot Lens is higher than that of the Linear Lens. The results gathered proved this conclusion. Table 4 shows the achieved temperatures when using Linear Lens as the light energy concentrator. Based on the result shown in Table 5, the highest temperature that the solar heater reached was 193.2 °C which is 47.4 °C lower than the highest temperature achieved when Spot Lens is added in the designed solar furnace as shown in Table 4.

| Fresnel Lens | Focal Length | Temperature |
|---|---|---|
| Spot | 30.48 cm | 240 °C. |
| | 24 cm | 130 °C |
| Linear | 60.96 cm | 193. 2 °C |
| | 63 cm | 130 °C |

**Table 6.** Temperature Equivalent every Length of Fresnel lens

E. Final Product of Solar heating The plastic (HDPE) is checked carefully to prevent it to burn inside the container due to maximum temperature reached by the solar heater using spot and linear Fresnel lens around 240°C and 190°C. The only required temperature to melt the HDPE is 130°C which is the ideal parameter to start to mold the HDPE inside the container using manual compression. The final output or product of the molded plastic materials is shown in figure 19.

(a) Top View

(b) Side View

(c) Bottom View

***Figure 19**. Different Views of Plastic lumber from HDPE plastic having dimensions of 50 mm x 70mm x 150 mm*

F. Compressive Strength

The compressive strength of the molded plastic lumber is 1.6MPa as measured using a Universal Testing Machine (UTM). This is the amount of stress it can withstand in actual use, Figure 20.

(a)


(b)

***Figure 14.** Actual compression and result of the plastic lumber.*

Analysis: Based on the data, the experimental compressive strength of plastic lumber did not reached the same value as compared to its theoretical value. One of the reasons is that, during the testing process, the plastic lumber slip before its start to break its body due to the inclination of its position in the machine during the compression. The plastic lumber is not completely solid due to some gaps in its body. The plastic lumber did not collapse completely but there was slight fracture on the surface. Also, the ability of the Universal Testing Machine to compress the plastic lumber is limited, it can only compress about 2 inches where the plastic materials were just starting to bend, and thus the plastic lumber shows its property of plasticity. V. Summary, Conclusion, Recommendation A. Summary of Experimentation The researchers conducted an experiment within two days. In the overall experiments, three set-ups test were done. First day of the experiment is testing the parabolic heater with closed container. The experiment starts at 10:00AM and ended at 11:00AM. with 5 minutes interval of the data gathering. Based on the data gathered, the temperature of the container increases for 25 minutes (27°C-60°C) and slowly decreases in the following 35 minutes (60°C- 30°C). Another set-up is done on that same time and different day. At this set-up, spot lens is used with the parabolic heater and the container is still closed. The same results as that of the first set-up. At first few minutes, the temperature of the container increases and then immediately decreases on the following minutes. The only difference in the second set-up is that it is faster to achieve its highest temperature than that of the first set-up. After 20 minutes the temperature of the container becomes 62.6°C. In the next day of experimentation, another two set-ups were done. The first one is still spot Fresnel lens with parabolic heater. The highest temperature achieved by the container is 68.4°C, the parabolic focal point highest temperature is 237.7 °C, and the parabolic highest temperature is 74.3°C. After reaching these temperatures, the temperatures slowly decreased. The last performed set-up was using a linear Fresnel lens only. At this set-up the temperature of the container increases greatly. The highest temperature being achieved is around 166.8 °C and 201.4 °C. B. Conclusion Based on the data gathered, the temperature produced by the designed parabolic solar furnace is not enough to achieve the melting point of HDPE plastics because it only achieved around $60^{o}$C. That measured temperature is very small compared to the required melting temperature of the plastic materials which is $130^{o}$C. But, by using Fresnel lens, a much higher temperature is achieved. Fresnel lens produced around $200^{o}$C, a preferred temperature in melting HDPE plastics. Therefore, forming a new useful product from the recycled plastic is possible because of the higher temperature produced by the Fresnel lens. The parabolic concentrator is then used in maintaining the temperature of the solar furnace because of an aluminium type of material can easily reject heat to the surroundings. The temperature produced by the lens is the main source of heat used in melting recycled HDPE plastics. The researchers also concluded that the product of the recycled plastics can be good alternative for any construction materials like wood, hollow blocks, etc. because it has a high compressive strength as of the conventional construction materials. For instance, instead of using wood to build a table, the product of the recycled plastics can be used as an alternative construction material. The benefit of using plastic lumber in the community is to reduce plastic waste (HDPE) in the landfill, conserve natural resources and reduce gas emissions. The use of the designed solar heater can conserve energy and decrease pollution if used for the community. C. Recommendation The design of the solar furnace needs some improvements to make it more efficient in melting plastics. These are some recommendations on how to improve the design of the solar furnace. First of all is the consideration of the material used. In the design, the researchers used an aluminium type of solar furnace. The disadvantage upon using aluminium materials is its ability to reject heat to the surroundings, so the effectiveness of maintaining the higher temperature is very much lowered Second, is the challenge on how to reduce the size of the HDPE plastics into tinier bits. The plastic waste materials must be shred into small pieces because, in the process of melting, the smaller the plastics, the faster it melts. Finally, a very important factor that must be considered in this study is the weather condition, especially in testing the solar furnace. Testing must always be done on sunny days because the design depends on the intensity of light coming from the sun.

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