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Low Cost Solar Parabolic Trough for Steam Sterilization

N. K. Sharma
Department of Mechanical Engineering, SRM University, Sonipat, Haryana, India
nksharma@srmuniversity.ac.in

Abstract— The objective of this study is to develop low cost solar parabolic trough that can be used for steam sterilization of medical instruments in small clinics where electricity is scarce and expensive. On the basis of theoretical concepts of parabola and focus-balanced parabola, the assembly of ribs and reflector sheet with evacuated tube and heat pipe has been done. Once, the parabolic trough is ready, it has been mounted on a trolley so that it can be moved easily from one place to another, according to the direction of sun light. The designed solar parabolic trough was integrated with pressure cooker under various setups and a number of experiments were conducted to test whether sterilization is taking place or not. To validate the sterilization process, tests were also conducted by placing the infected medical instruments. It was found that the solar parabolic trough developed in this study was able to generate and maintain steam at 121^0 C for 15 minutes. Thus, the solar parabolic trough developed was effective in sterilizing the medical instruments.

Keywords—Solar, Parabolic Trough, Low Cost, Steam Sterilization

1. INTRODUCTION

In a commercial application of parabola, reflective parabola is one of the cost optimized way to concentrate rays. Using this property of parabola, different figures can be developed to harness solar energy. When a parabolic shape is rotated around its center axis, a Parabolic dish is developed. When the parabola is stretched at right angles, it gives a parabolic trough. For application purposes, parabolic troughs are easier and cheaper to operate and manufacture than parabolic dish because the dish requires tracking on two separate axis, while a trough needs tracking on a single axis.

Thus, using this concept of parabola and the focus-balanced reflector, the parabolic trough in this study has been developed. For steam sterilization, the medical instruments are to be kept for 121^0 C for a minimum of 15 minutes [1]. The sterilization cycle time is assumed to be 75 minutes, 60 minutes for reaching 121^0 C and 15 minutes for maintaining temperature at 121^0 C. The size of parabola has been calculated accordingly. Two important things to be considered while making Focus Balanced Parabola are as follows:

- To minimize the force required to move the parabolic trough about its axis, the parabolic trough should have its center of mass at its focus. Thus, the focal length was picked around which the arms of the parabola were bent in such a manner that one half of the weight of the setup was on one side of the focal line and one half on the other side.
- The parabola should be as flat as possible so that the largest aperture can be obtained. A large aperture makes good use of the reflective surface as it collects more sunlight. The aperture area is aperture times its length [2].

These two considerations, though equally important, contrast with each other. Thus, there needs to be such a situation where a large focal length is there while simultaneously having an adequate aperture length.

The following equation is used to draw the parabola. If the parabola is pointed upward and the vertex is located at x=0 and y=0, then, $\mathbf{y = x^2/4f}$, here y is the vertical distance of a point on the parabola, x is the horizontal distance and f is the focal length.

The focal line is located by the hangers, in other words, the hangers hold the collector tube along the focal line to get maximum exposure to the concentrated sunlight. The parabolic collectors are more or less balanced so that the force required to turn the parabola on its focal point is minimal. As F moves further from the vertex, the parabola becomes flatter. As F moves closer to vertex, the “arms” of the parabola also move closer. Figure 1 presents the focus balanced parabola.

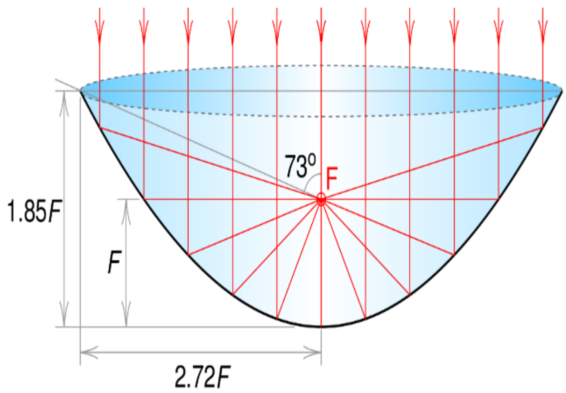

Fig. 1. Focus Balanced Parabola [3]

2. DESIGN CONSIDERATIONS FOR PARABOLA

1. Low Cost
2. Local Material
3. Dish vs. Parabolic Trough
4. Easy to Assemble
5. Size of the parabola on the basis of energy required by the Autoclave
6. Structurally Strong and Light Weight

A. Estimated Area of Parabola

The estimated heat losses from the vessel are convection heat loss, radiation heat loss, and the steam outflow heat loss. Assuming the capacity of sterilization vessel of 10 Litre capacity,

Heat Loss from Vessel during Sterilization Cycle of 75 Minutes = $Q_{convection} + Q_{radiation} + Q_{steam\ loss}$

The maximum solar irradiation on earth surface is 1000 W/m^2 and assuming the efficiency of parabola to be 30 %, therefore, the estimated area of the solar collector is:

$$\text{Area} = \frac{Total\ Heat\ Loss\ in\ Watts}{Solar\ Irradiance\ in \frac{W}{m2}\ x\ Efficiency\ of\ parabola}$$

Accordingly, the area comes out to be 1.8 m^2. However, the values of the solar irradiation and efficiency of parabola is on higher side.

B. Size of Parabola

The standard anodized aluminium sheet with size of 1250 mm x 1220 mm is used. Considering the arc length of the parabola is 1250 mm, the focus- balanced parabola is formed at 183 mm focal length with 1.85 F on y-axis and 2.72 F on x-axis (Refer Figure 1 of Focus Balanced Parabola). The arc length has been calculated by using the on- line arc length calculator [4]. Thus, by taking 183 mm as the focal length, the wastage of the reflective sheet is minimized. The wastage in the MDF Board (Medium Density Fiber Board) is also minimum while cutting the ribs from the standard size of 7 x 4 feet of MDF Board. When the focal length is 183 mm, following are the dimensions of the parabola:

F = 183 mm

Length along Axis = 1.85F on y-axis = 338.5 mm

Width or Perpendicular Cord Length = twice of 2.72F on x-axis = 995.5 mm

For these dimensions, arc length is 1248 mm, nearest value to the sheet size.

Since, the projected area of the solar collector/parabola is 1.8 m^2 and the length of ETC tube is 1.8 m, the parabola shall be constructed with length of 1.8 m and width of 1m. The diameter of ETC tube is 58 mm which results in concentration ratio as 17 [5].

3. DRAWING OF PARABOLA

The parabola was designed by calculating the different values of the coordinates using the equation, $\mathbf{y = x^2/4f}$. Values of x are taken 5 mm apart from each other. These points were then plotted on a drawing sheet and joined together. Figure 2 shows the drawing of parabolic focus balanced reflector.

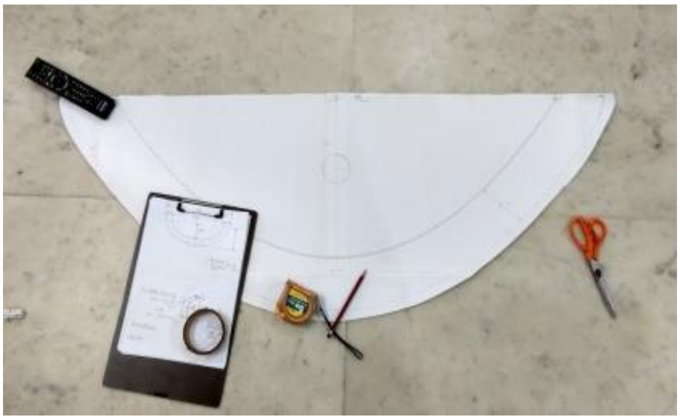

Fig. 2. Drawing the Profile of Focus - balanced Parabolic Reflector

4. FABRICATION AND ASSEMBLY

A full size paper pattern is transferred on the wooden board to make a template to help make multiple near identical parts. The marking template is quite thin. The template has been made from 3 mm plywood. To transfer the paper pattern to the template material, the paper pattern has been glued to the template material by using fevicol. After cutting, the finishing is done using sandpaper to remove irregularities on the inner surface. Also, using filler, any imperfections in the edges are repaired. This is then allowed to harden and then sand smooth.

An accuracy of inner surface is important. The most vital part of the template is the edge that forms the solar reflector (the top edge). The accuracy required for the top edge is important and is not required for the bottom edge, though tidiness would increase the aesthetic property of the finished parts.

A. Rib and Hanger Material

The ribs are cut from sheet material MDF wood of 10mm thickness. Other materials such as HDPE (High Density Polyethylene), molded plastic, aluminium, or steel could also be used. But, in this study, focus is on materials that are low cost and people can procure easily and work upon them without much efforts through conventional woodworking and hand tools.

B. Symmetry and Accuracy of Ribs

To check the accuracy of the ribs and profile of focus-balanced parabola, following procedure was followed:

- Place the rib on a table.
- Draw grid lines on the table.
- Draw focal point (focal circle).
- Using a laser beam and mirror, it is checked that the laser light passes through the focal point (focal circle), as shown in Figure 3.

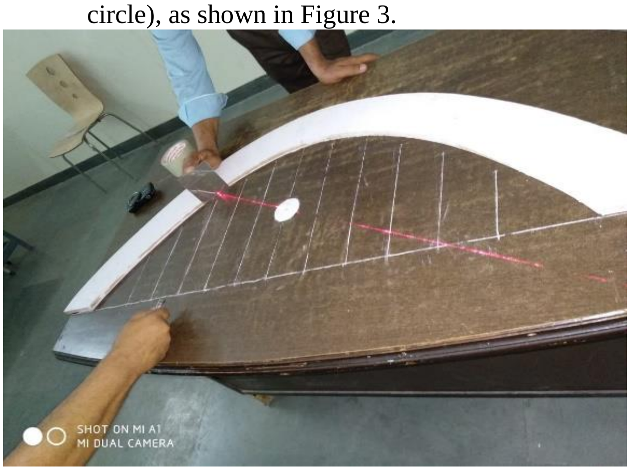

Fig. 3. Checking Accuracy of Ribs using Laser Pointer

C. Assembly of Ribs

The Parabolic Trough was fabricated using wooden parabolic frames made of MDF Board of 10 mm thickness. The wooden parabolic frames are simple and light weight. The design has been made using a pattern method. A pattern or template has been drawn on chart paper as discussed earlier, and accordingly, the wooden parabolic frames were then cut by machine. These ribs were then painted. After the paint dried, these wooden parabolic frames were joined together with aluminium angles and screws, as shown in Figure 4.

Fig. 4. Assembly of Wooden Ribs and Diagonal Checking with Thread

The robust wooden ribs, although light-weight, are assembled in such a manner that they not only provide a strong grip of the reflective sheet but also support it properly from below. Seven such Wooden Parabolic Reinforcements were used to make the Parabolic Trough. Small wooden blocks and threads have also been used (Figure 5) to fix the reflective sheet with the ribs to arrest any spring back action. This trough is mounted on a trolley for shifting and easy manual orientation.

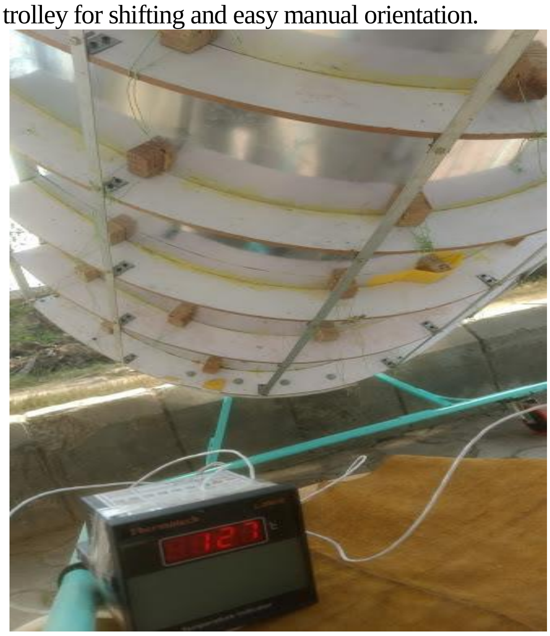

Fig. 5. Small Wooden Blocks and Threads to Fix Reflective Sheet with Ribs

D. Hangers

The reflector hangers were created in the same way the ribs were created. Two hangers are required for each side of the reflector assembly. Following are the steps for creating hangers:

- Put template and trace the outline of the hanger from the sheet material. Cut out the traced hangers with the help of a saw. Try to cut close to the marked pencil outline, as it will remove most of the excess material.
- After smoothening out the hangers, four holes are drilled in each of the hanger. The holes are 6 mm in diameter and situated at the bottom to interlock with a rib. Another hole is drilled on the top for the collector tube.

E. Reflector Side Channels

The reflector side channels are positioned on the sides of the reflectors and are the same length as that of the reflector. A reflector would have 4 side angles of size 20 mm which are screwed to each rib. The side channels are of the same length as the reflective surface and the top 2 channels hold the reflective sheet firmly with the ribs. The reflective sheet is bent into a cylindrical shape and screwed to the side channels. It actually increases the strength and rigidity of the structure.

F. Reflector Sheet

The reflective aluminium sheets of 0.4 mm thickness, especially created for outdoor usage like the parabolic reflectors, have long lasting coatings and it is made from a compatible material (anodized aluminium) making it resistant to galvanic corrosion. The size of sheets used are of 1250 mm x 1220 mm. This material should be handled with care as it can be easily distorted if not handled properly. Once the material is distorted, it loses its reflective properties in that particular region.

In order to cut the reflector material properly, it should be cut as squarely as possible while having high accuracy as well. As the reflector material is thin and have sharp edges, it should be cut wearing gloves.

The reflector sheet can sag at various places due to its thin size. Some gaps may form out near the channels. In such a case, although most of the inner parabolic sheet would work properly, but in the areas in which the sagging occurs the reflected sunlight from the sheet would not reach the focus of the parabola and potential thermal energy may be lost. This problem can be tackled either by adding more ribs to the assembly and uniformly spreading out to provide proper support to the thin reflector sheet or by using a thicker reflective material or perhaps, the easiest way of them all is to glue it up. On the back side of the reflector, Fevicol Heatx adhesive has been applied so that it gets firmly fixed to the side channel and ribs.

5. EVACUATED TUBE COLLECTOR

With the help of an insulated collector we can reduce the thermal losses in situations where the weather is cold or when we experience some wind. Moreover, with the help of insulated collectors we can achieve higher temperatures. The evacuated tube solar collectors use glass thermos like bottles which have a selective coating on the inside to confine the solar heat. The evacuated tube solar collector includes a heat pipe inside. This heat pipe is used to conduct the heat to a metal bulb at the end which is thermally coupled with the autoclave.

The evacuated tubes are highly efficient collectors of solar thermal energy. When sun rays strike these tubes, the energy gathered is used to heat working fluid in the heat pipe. This creates a thermosiphon effect. The working fluid (Glycol + Water) in the heat pipe continues to be heated until it evaporates and gets superheated. The surface of the evacuated tubes allows visible light and UV radiation to pass into the tubes and is absorbed as heat. The surface does not allow the radiation to pass out of the tubes. The vacuum between the glass layers acts as an extremely effective thermal insulator and about 92 % of the energy absorbed is transferred to the heat pipe. The glass in the tube can withstand impact from the hailstones up to 25 mm diameter. These tubes can operate in all kinds of weathers like cold, cloudy and rainy conditions apart from sunny conditions which are the optimum conditions. This is due to the vacuum which does not allow heat loss due to conduction or convection. The effectiveness of ETC tube depends on the insolation level of the location, which is a measure of the amount of solar radiation striking an area. Thus, the ETC tube (Figure 6) can be used throughout the year. The evacuated tube is of diameter 58 mm and 1.8 m length. The evacuated solar collector tubes are not expensive and are easily available.

Fig. 6. Evacuated Tube

Concentrated heat from the sun can cause the collector tube to rapidly increase temperature of heat pipe. It is important to be careful not to come into contact with the bulb of heat pipe. During the experiments, the temperature of the bulb of heat pipe was measured above 200^0 C.

6. HEAT PIPE VACUUM TUBE

The heat pipe is positioned in the evacuated tube with the help of aluminium fin, as shown in Figure 7. The heat pipe is hollow with the space inside evacuated, same as the solar tube. In case of heat pipe, the goal is not the insulation but to alter the state of the liquid inside. Inside the heat pipe, there is a small quantity of purified water and some special additives. At sea level, the water boils at 100^0 C. Water boils at a lower temperature with decreased air pressure, by evacuating the heat pipe. So, when the heat pipe is heated above 30^0 C, the working fluid in it vaporizes. This vapour rapidly rises to the top of the heat pipe transferring heat. As the heat is lost at the condenser (top), the vapour condenses to form a liquid (water) and returns to the bottom of the heat pipe to once again repeat the process.

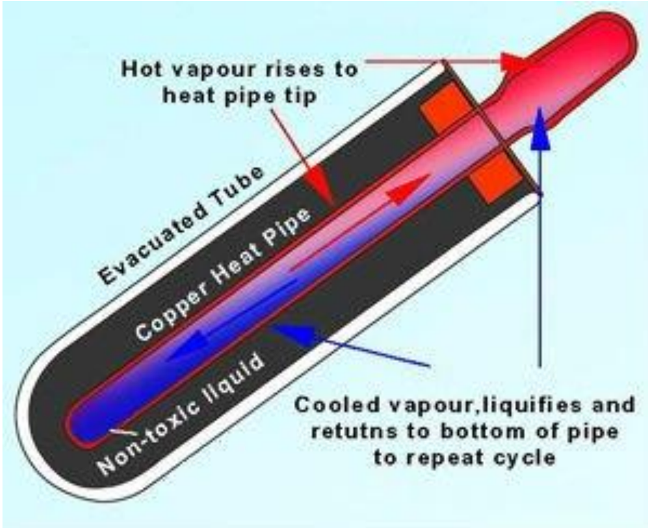

Fig 7. Working of Heat Pipe [6]

7. ASSEMBLY OF TROUGH WITH EVACUATED TUBE

Utmost care is required while handling and fitting the ETC tube in the Trough. Since there is vacuum in the glass tube, it would implode if the tube breaks due to mishandling. First, the polyethylene pipe is to be fixed in the hollow pipes at both ends of the hanger and then the tube should be put inside the hanger brackets. To check that the ETC pipe is fitted in line with focal point, the gap is measured between the bottom of tube and the reflective surface. The correction of alignment is done by adding the pieces of polyethylene in the gap between ETC pipe and pipe support of hangers.

8. MOUNTING PARABOLIC TROUGH ON TROLLEY

After fitting the Evacuated Tube on Parabolic Trough, the apparatus was mounted on a trolley so that it can be moved easily from one place to another and also from one direction to another with the movement of sun to take maximum advantage of sunlight. The apparatus mounted on the trolley is shown in Figure 8.

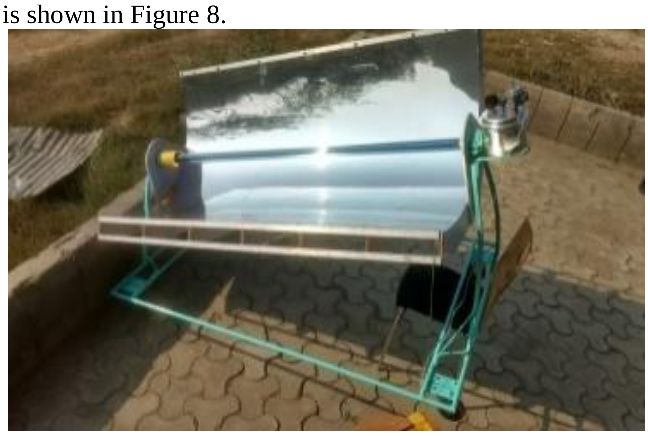

Fig. 8. Apparatus Mounted on Trolley

9. COST ESTIMATION

The estimated material cost of solar parabolic trough developed in this study is presented in Table 1.

TABLE 1: COSTING OF PARABOLIC TROUGH AND TROLLEY WITH WHEELS

S. No.	**Item**	**Cost (Rs.)**
1.	Pre Anodized Aluminium Sheet	2,800
2.	Ribs	2,500
3.	Aluminium Angle	700
4.	Aluminium Strip	150
5.	Evacuated Tube	650
6.	ETC Holding Bracket, Trolley Mounting Bracket	700
7.	Bolt and Screw	250
8.	Paint and Adhesives	800
9.	Trolley with Wheels	3,500
10.	**Total**	**12,050/-**

10. TESTING THE EFFECTIVENESS OF DEVELOPED SOLAR PARABOLIC TROUGH

The designed solar parabolic trough was integrated with pressure cooker under various setups and experiments were conducted to test whether sterilization is taking place or not. To validate the sterilization process, tests were also conducted by placing the infected medical instruments. It was found that the solar parabolic trough developed in this study was able to generate and maintain steam at 121^0 C for 15 minutes and, therefore, can be effectively used for sterilization purposes. These experiments were conducted in C4D Lab of SRM University, Sonipat, Haryana.

11. SUMMARY AND CONCLUSION

The concept of parabola, focus-balanced parabola and the process of making the parabolic trough by using these concepts has been explained. The parabolic trough has been designed and assembled with wooden ribs, reflector sheet, evacuated tube and heat pipe. After making the parabolic trough, it has been mounted on the trolley so that it can be moved easily from one place to another. The solar parabolic trough developed in this study was able to generate and maintain steam at 121^0 C for 15 minutes and, therefore, can be effectively used for sterilization purposes.

The parabola has been fabricated and assembled using ordinary tools, some materials from a hardware store and a few special parts. Most of the material used is available locally. The parabola designed is easy to build, versatile, light and strong. It has been made with commonly available parts which are easier to find anywhere.

ACKNOWLEDGMENT

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