Design and construction of parabolic solar heater using polymer matrix composite

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Abstract

A parabolic dish is a type of concentrating reflective device that uses the shape of a circular paraboloid to collect or project energy such as light, sound, or radio waves. The parabolic reflector transforms an incoming plane wave traveling along the axis into a spherical wave converging toward the focus. In this work concentrating dish was moulded from polyester resin reinforced with fiber glass mat and inner surface lined with Aluminum foil to increase the reflectivity. The design was made up of a moulded dish of 246cm diameter with a height of 58.2cm which has a concentration factor of 54.9. The collector was mounted on a site with latitude 6°40′22.19″ and longitude 3°09′47.12″ and water at 27^{0}C was heated to a temperature of 85^{0}C within 20 minutes.

Key words: *Solar energy, aluminium foil, polymer matrix composite (PMC), parabolic dish, polyester*

1. Introduction

World energy use increased more than tenfold over the 20th century, predominantly from fossil fuels (i.e. coal, oil and gas) and with the addition of electricity from nuclear power. In the 21st century, further increases in world energy consumption can be expected, much for rising industrialisation and demand in previously less developed countries, aggravated by gross inefficiencies in all countries. Whatever the energy source, there is an overriding need for efficient generation and use of energy (John Twidell et al, 2006).

The Sun is the largest energy source, annually producing 3.9×10^{24}J = 1.08×10^{18}KWh of solar energy which reaches the surface of the Earth. This is about 10,000 times more than the annual global primary energy demand and much more than all available energy reserves on earth; therefore using one ten-thousandth part of the incoming sunlight would cover the whole energy demand of mankind**.** Nigeria receives about 5.08×10^{12} kWh of free energy per day from the sun, if solar devices with just 5% efficiency are used to cover only 1% of the country's surface area then 2.54×10^{6} kWh of electrical energy can be obtained from solar energy; this amount of electrical energy is equivalent to 4.66million barrels of oil per day (Sambo and Doyle, 1986).

This energy is expected to be the foundation of a sustainable energy economy, because sunlight is the most abundant renewable energy resource; additionally, solar energy is harmless to the environment in terms of pollution and ecological stability.

There is a distinction between direct and indirect solar energy. Technical systems using direct solar energy convert incoming solar radiation directly to useful energy, for instance electricity or heat. Wind, river water and plant growth are indirect forms of solar energy. Here natural processes convert solar energy into other types of energy. Technical systems can use these indirect types of solar energy as well.

Solar thermal energy derived from the sun's heat has been used for centuries by ancient people for heating and drying. More recently, in a wide variety of thermal processes solar energy has been developed for power generation, water heating, mechanical crop dying, and water purification, among others.

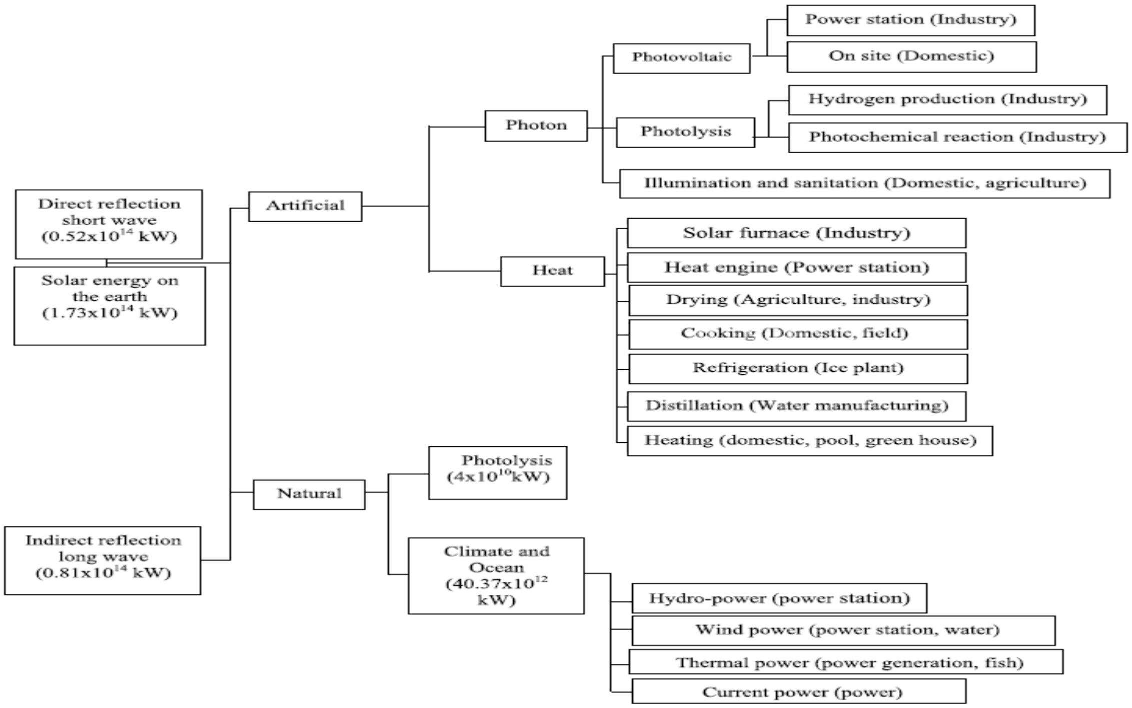


Figure 1: Solar energy distribution and utilization (Ohta 1979)

In our world today, a common use of solar energy is for heating air and water; dwellings in cold climates need heated air for comfort, and in all countries hot water is used for washing and other domestic purposes. For example, about 30% of the UK's energy consumption is beneficial for heat in buildings and of Australia's energy consumption, about 20% is used for heating fluids to 'low' temperatures *(*100^{o}C*)*. Because of this, the manufacture of solar water heaters has become an established industry in several countries, especially Australia, Greece, Israel, USA, Japan and China. The great majority of solar water heaters are for domestic properties, despite large volumes of hot water being used for process heat in industry (John Twidell et al, 2006).

Given the range of working temperatures of solar thermal processes, the most common applications are:

- For less than 100^{o}C: water heating for domestic use and swimming pools, heating of buildings, and evaporative systems such as distillation and dryers;
- For less than 150^{o}C: air conditioning, and heating of water, oil, or air for industrial use;
- For temperatures between 200^{o}C and 2000^{o}C: generation of electrical and mechanical power; and
- For less than 5000^{o}C: Solar furnace for the treatment of materials.

Solar powered devices are the most direct way of capturing the sun's energy, harnessing it, and turning it into something useful. These devices capture the sun's energy and directly transform it into a useful energy source. A solar powered device is said to be **passive** if the solar heat is absorbed and utilized without significant mechanical pumping and blowing; but if the solar heat is collected in a fluid, usually water or air, which is then moved by pumps or fans for use, the solar system is said to be **active**. The general principles and analysis that apply to solar water heaters apply also to many other systems which use active and passive mechanisms to absorb the Sun's energy as heat, e.g. air heaters, crop driers, solar 'power towers', solar stills for distilling water, solar buildings; (John Twidell et al, 2006)

The following technologies can utilize direct solar energy:

- Solar thermal power plants
- Photolysis systems for fuel production
- Solar collectors for water heating
- Passive solar heating systems
- Photovoltaic, solar cells for electricity generation.

1.0. AIM

The overall aim of this project is to harness part of the sun's energy to heat up water for domestic purposes.

1.1. Objective

The objective of this project is to design and build a parabolic solar dish of 2.46m diameter that takes the sun's energy by concentrating its rays to the parabola's focal point so as to heat up water to temperatures between 82-121ºC (180-250ºF).

1.2. Scope and de-limitation of work

This project would only cover the design and construction of a parabolic solar dish that would serve as a collector and concentrator of the sun's energy, choice of materials for better performance, calculations as relating to the designed system such as the amount of heat energy that can be generated by this system, and the amount of time it would take to achieve the amount of heat energy needed. The obtained temperatures can be applied as follow:

- For less than 100^oC: water heating for domestic use and swimming pools, heating of buildings, and evaporative systems such as distillation and dryers;
- For less than 150^oC: air conditioning, and heating of water, oil, or air for industrial use;

1.3. Importance

The importance of this project is harnessing the sun's thermal energy for heating of water and other fluids for domestic and industrial purposes.

2. Literature review

This project required a general research, to discover and utilize the past findings of others, this revealed articles discuss solar technologies and their construction. This served as a great starting point for understanding some of the components of designing any type of solar system; this included reviews on the design elements and materials needed for the reflector and absorber for optimal performance. The research also revealed in-depth consideration on several variation of solar heating systems and clear explanations on some underlying principles of how these systems work. A bibliography of the research resources used for this project is located at the end of this report.

2.1. Solar energy collectors

Solar collectors are devices which take the solar energy from over a wide area, and concentrate it into a smaller area. These devices are said to be **passive** if the solar heat is absorbed and utilized without significant mechanical pumping and blowing; but if the solar heat is collected in a fluid, usually water or air, which is then moved by pumps or fans for use, the solar system is said to be **active**. These devices can collect solar energy for the production of either heat or electricity.

The Design methods of solar energy collectors include:

- flat collectors,
- evacuated tubes, and
- Concentrators.

2.1.1. Flat collectors

Flat collectors work with both direct and diffused light. They provide low temperature heat (less than 70^0C) useful for ambient heating, domestic hot water systems, and swimming pools. This type of collector is affected by weather, and its efficiency decreases if large temperature rises are demanded.

Simple collectors are black plastic hoses exposed to the sun. More elaborate collectors use both front and back insulation to reduce heat losses. Collectors may heat water directly or may use an intermediate heat transfer fluid.

The figure below shows a cross section through a typical flat collector. Light and inexpensive aluminum is used extensively; however, it tends to be corroded by water. Copper is best suited for pipes. If an intermediate heat exchange fluid is employed, aluminum extrusions that include the channels for the liquid are preferred. Some panels use a thin copper sleeve inserted into the aluminum tubing; panels can be black-anodized or painted.

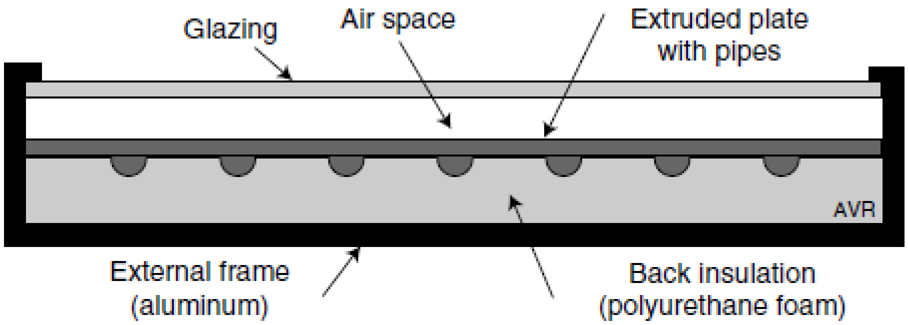


Figure 2.1: Cross section through a typical flat collector (DOE-EREC, 1996)

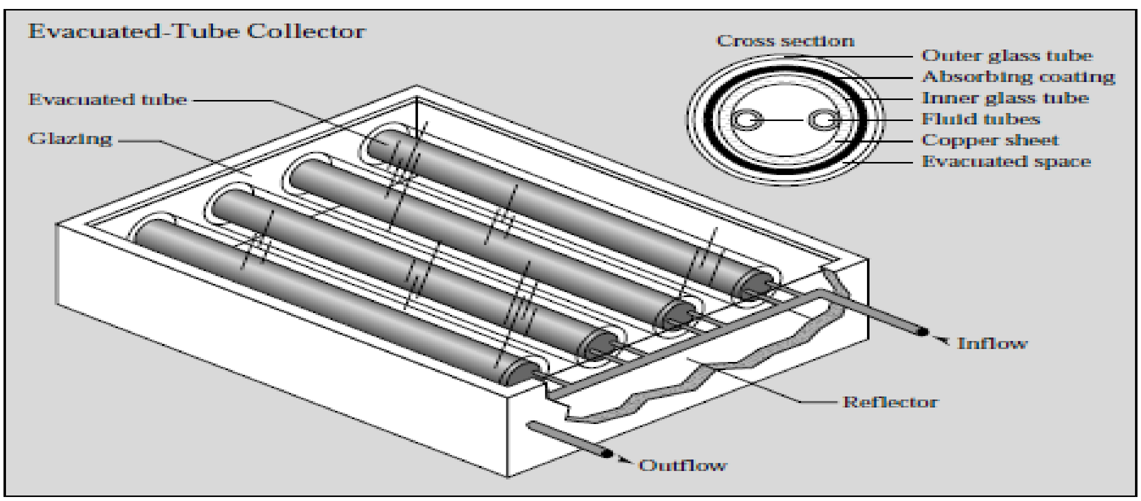
Flat-plate collectors fall into two basic categories: liquid and air. And both types can be either glazed or unglazed. Unglazed collectors are commonly used to heat swimming pool water. No glazing is needed because the system is used when both outdoor temperatures and solar radiation levels are high (DOE-EREC, 1996).

2.1.2. Evacuated tubes

This type of collector consists of two concentric cylinders, the outer one of glass and the inner, a pipe through which the liquid flows. They bear an exterior likeness to fluorescent lamps. A vacuum is established between the two cylinders therefore conductive and convective heat losses are eliminated because there is no air to conduct heat or to circulate and cause convective losses. There can still be some radiant heat loss (heat energy will move through space or vacuum from a warmer to a cooler surface). However, this loss is small and of little effect compared with the amount of heat transferred to the liquid in the absorber tube reducing the convection heat losses.

Evacuated tubes are non-directional and can heat liquids to some 80^0C. Reflectors placed behind the evacuated tubes can help to focus additional sunlight on the collector.

These collectors are more efficient than flat-plate collectors for two main reasons. First, they perform well in both direct and diffuse solar radiation; also due to the minimal heat losses to the outdoors due to the vacuum, makes these collectors particularly useful in areas with cold, cloudy winters. Second, because of the circular shape of the evacuated tube, sunlight is perpendicular to the absorber for most of the day. (DOE-EREC, 1996)



An evacuated-tube collector generally consists of a fluid-filled absorber tube surrounded by a vacuum.

Figure 2.2: An Evacuated Tube Collector (DOE-EREC, 1996)

2.1.3. Concentrators

Concentrating collectors use mirrored surfaces to concentrate the sun's energy on an absorber called a receiver. Concentrating collectors also achieve high temperatures, but unlike evacuated-tube collectors and flat plate collectors, they can do so only when direct sunlight is available, with the result being that their performance is poor on hazy or cloudy days.

Some designs called a point focusing concentrators (3-D) concentrate solar energy onto a focal point, while others called a line focusing concentrator (2-D) concentrate the sun's rays along a thin line called the focal line. The receiver is located at the focal point or along the focal line. A heat-transfer fluid flows through the receiver and absorbs heat.

Concentrators are most practical in areas of high insolation (exposure to the sun's rays), such as those close to the equator and in the desert areas; and they perform best when pointed directly at the sun. To do this, these systems use tracking mechanisms to move the collectors during the day to keep them focused on the sun. Single-axis trackers move east to west; dual-axis trackers move east and west and north and south (to follow the sun throughout the year).

Concentrators are used mostly in commercial applications because they are expensive and because the trackers need frequent maintenance. Some residential solar energy systems use parabolic-trough concentrating systems. These installations can provide hot water, space heating, and water purification. Most residential systems use single-axis trackers, which are less expensive and simpler than dual-axis trackers. (Doe-Erec, 1996)

Two important parameters describe the collector performance:

- Concentration, *C*, and
- Acceptance angle, *θ*.

Concentration (C): can be defined as either the ratio of the aperture area to the receiver area or as the ratio of the power density at the receiver to that at the aperture.

$C_a = \frac{area of aperture}{area of receiver}$ OR $C_d = \frac{power density at receiver}{power density at aperture}$; $C_a \neq C_d$

These definitions are not equivalent; the latter concentration is preferable.

Acceptance angle(θ): is the angle through which the system can be misaimed without (greatly) affecting the power at the receiver.

There is a theoretical relationship between the concentration and the acceptance angle for the ideal case:

- $C_{ideal} = (\sin\theta)^{-1}$ for a 2-D concentrator……………………….2.1
- $C_{ideal} = (\sin\theta)^{-2}$ for a 3-D concentrator…………………………..2.2

It is instructive to calculate the maximum temperature that a receiver can attain as a function of concentration. An ideal receiver will work in a vacuum (no convection losses) and will be perfectly insulated (no conduction losses). Nevertheless, radiation losses are unavoidable. They will amount to

$Pr = \sigma\varepsilon T^4$ Wm^{-2}……………………………..2.3

where ε is the emissivity (taken as unity)and σ is the Stefan–Boltzmann constant (5.67 × 10^{-8} W m^{-2}K^{-4}).

The power density at the receiver (assuming no atmospheric losses) is

P_{in} = 1360C Wm^{-2}……………………………..2.4

In equilibrium, $P_r = P_{in}$,

$\sigma T^4 = 1360C$ ……………………………………2.5

or,

$T = (2.4 \times 10^{10}C)^{1/4} = 394\ C^{1/4}$…………………..2.6

With unity concentration (flat plate collector), T = 393K or 120 C.

When the concentration is raised to 1000, the maximum temperature theoretically attainable is 2200 K. Were it possible to construct a collector with a concentration of 1 million, the formula would predict a receiver temperature of 12,400 K. This would violate the second law of thermodynamics because heat would be flowing unaided from the cooler sun (6000 K) to the hotter receiver. Clearly, the upper bound of the receiver temperature must be 6000 K.

One can arrive at the same conclusion by considering the expression for C_{ideal}. The solar angular radius, as seen from Earth, is 0.25^o. Thus, the minimum acceptance angle that allows collection of light from the whole sun is 0.25^o, and this leads to a C_{max} = 52,000 for a 3-D collector and 230 for a 2-D collector as calculated from Equations 2.1 and 2.2. A concentration of 52,000 corresponds to a T_{max} of 5900K (Equation 2.6), just about right.

Numerous reasons cause the concentration (in terms of power densities) to be less than ideal:

1. Reflector shape and alignment errors
2. Less than perfect reflector surface reflectivity
3. Tracking errors
4. Atmospheric scatter
5. Atmospheric absorption

(Aldo V. Da Rosa, 2009)

2.2. Parabolic solar collector

A parabolic reflector (or dish or mirror) is a type of concentrating reflective device that uses the shape of a circular paraboloid (i.e. surface generated by a parabola revolving around its axis) to collect or project energy such as light, sound, or radio waves. The parabolic reflector transforms an incoming plane wave traveling along the axis into a spherical wave converging toward the focus. Conversely, a spherical wave generated by a point source placed in the focus is transformed into a plane wave propagating as a collimated beam along the axis. [Wikipedia, 2010]

Satellite dishes are used to concentrating waves emitted from satellites far above the earth surface into a focal point to strengthen the signal. Radio and television telescopes perched up high on hillsides also take signals from a wide area, focusing it down to a small point. These technologies are taking weak signals from outer space to a fine point where they can be processed. Solar concentrators using parabolic dishes are exactly the same with these technologies, the difference being the medium used to coat the dishes. Rather than being reflective to radio waves, the coatings used to coat a parabolic solar reflector are mirrors.

2.2.1. Historical background of parabolic reflectors

The principle of parabolic reflectors has been known since classical antiquity, when the mathematician Diocles described them in his book 'On Burning Mirrors' and proved that they focus a parallel beam to a point. Archimedes in the third century BC studied paraboloids as part of his study of hydrostatic equilibrium, and it has been claimed that he used reflectors to set the Roman fleet alight during the Siege of Syracuse. This seems unlikely to be true, however, as the claim does not appear in sources before the 2nd century AD, and Diocles does not mention it in his book. Parabolic mirrors were also studied by the physicist Ibn Sahl in the 10th century. James Gregory, in his 1663 book Optica Promota (1663), pointed out that a reflecting telescope with a mirror that was parabolic would correct spherical aberration as well as the chromatic aberration seen in refracting telescopes. The design he came up with bears his name: the "Gregorian telescope"; but according to his own confession, Gregory had no practical skill and he could find no optician capable of actually constructing one. Isaac Newton knew about the properties of parabolic mirrors but chose a spherical shape for his Newtonian telescope mirror to simplify construction. Lighthouses also commonly used parabolic mirrors to collimate a point of light from a lantern into a beam, before being replaced by more efficient Fresnel lenses in the 19th century (Wikipedia, 2010).

Back in the 1800s a Frenchman named Augustin Mouchot was actively experimenting with solar dishes to concentrate the sun's energy. Mouchot was concerned that coal was all going to be used up and that "Peak coal" was approaching. He said at that time "Eventually industry will no longer find in Europe the resources to satisfy its prodigious expansion, Coal will undoubtedly be used up." A little later in 1882, Abel Pifre, Mouchot's assistant, demonstrated a printing press in the Tuilleries Garden, Paris, powered by the sun, using a 3.5m diameter concave concentrating dish. At the focus of this concentrating furnace, was a steam boiler which provided steam for the printing press (Gavin, 2007).

Parabolic mirror surfaces are used to focus energy efficiently and accurately; the most common modern applications of the parabolic reflector are in satellite dishes, car headlights, astronomical telescopes, spotlights, parabolic solar heater, reflecting telescopes, radio telescopes, parabolic microphones, and many lighting devices such as spotlights, car headlights and LED housings. The Olympic Flame has been lit using a parabolic reflector concentrating sunlight. (Wikipedia, 2010)

2.2.2. The principle of the parabola

The parabolic reflector functions due to the geometric properties of the paraboloidal shape: if the angle of incidence to the inner surface of the collector equals the angle of reflection, then any incoming ray that is parallel to the axis of the dish will be reflected to a central point, or "focus". Because many types of energy can be reflected in this way, parabolic reflectors can be used to collect and concentrate energy entering the reflector at a particular angle. Similarly, energy radiating from the "focus" to the dish can be transmitted outward in a beam that is parallel to the axis of the dish. (Wikipedia,2010)

When Sun light (parallel rays) falls onto a correctly aligned parabolic mirror it will be reflected back towards a single point known as the focus. The parabolic mirror therefore directs the energy arriving over its surface to a 'hot spot' at the focus, so as to heat something.

The basic shape of a parabola is derived from the equation:

$$Y = X^2/4p$$

Where **X,** represents the distance away from the mirror centre and **Y**, represents the 'height above' the centre, see figure 1 and 2. The constant **p** is known as the focal length - the distance from the origin to the focus point.

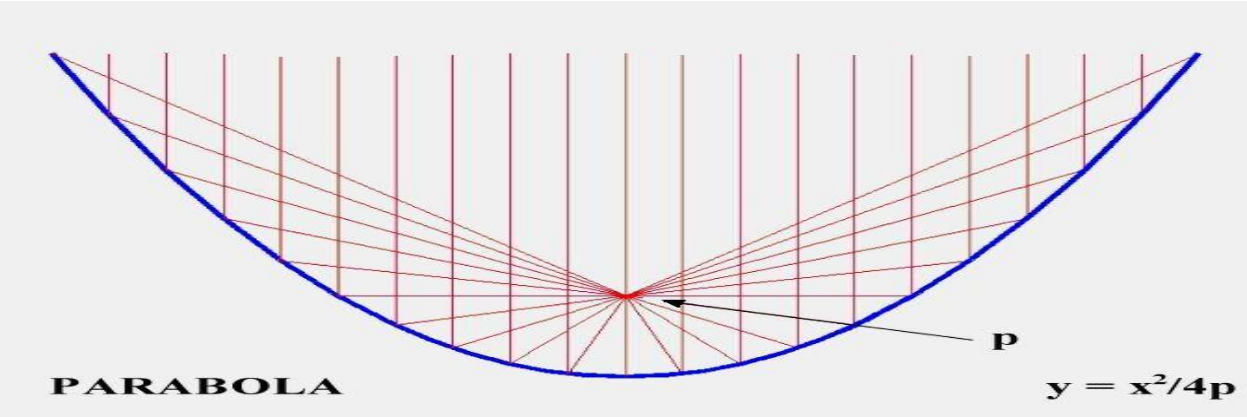


Figure 2.3: The basic geometry of a parabola mirror

Light rays coming from infinity will tend to be reflected towards a point called the focus.

To make a parabolic reflector in terms of its Diameter D, (i.e. having maximum X = D/2), height above origin **Y**, and focal length **p**, then equation above becomes: $p = D^2/16Y$

A focal length **p** is chosen; variables of X are chosen (i.e. from 0, 5, 10, 15...); then the corresponding values of Y are obtained from the equation above. The parabolic shape is then obtained from the X and Y values.

2.2.3. Types of parabolic collectors

There are 2 main designs of parabolic solar collectors these are:

2.2.3.1. Parabolic Dish:

This is also known as a point focus type collector; a practical application of a parabolic dish is a flashlight lens, which is used to transform a point source of light into a parallel beam. Since sunlight radiation is essentially parallel it may be concentrated at the focal point of the lens. As a matter of fact a tiny flashlight lens may be used as a cigarette lighter by substituting a cigarette for the bulb and by pointing the lens in the direction of the sun. A type of solar reflector dish concentrator may also be made by lining the inside of a cardboard box with aluminum foil.

Higher temperatures can be achieved with a parabolic dish as they focus the entire solar capture area to a point i.e. 1500^0C. Microwave radio antennas also use a parabolic dish to concentrate the incoming radio beam to a point to recover the diffused signal. The dish itself is not frequency selective but the "pick-up" at the focus is. Parabolic dishes develop solar concentrating factor of around 600 – 2000, depending on its size and focus. A parabolic dish with receiver for Stirling engine is the Plataforma Solar de Almeria – distal I and II.


Figure 2.4: Parabolic dish (Plataforma Solar de Almeria – distal I and II)

2.2.3.2. Heliostat

A field of heliostats tracks the sun using flat or slightly curved mirrors and focuses energy on to a stationary parabolic concentrator which refocuses energy to the central receiving tower; they are used with solar furnaces and power towers. Very high temperatures are achieved and as there are usually many collectors, the power level is enormous. The receiving target transfers the power away through a "working" fluid" to drive a turbine to generate electricity. A number of pilot plants have been built and have operated successfully for many years. 'Solar one" and "Solar two" are examples of the biggest solar power stations around; solar two is located in California near Barstowit incorporates thousands of tracking mirrors (heliostats) and has a system capacity of 10 MW. The working fluid (molten nitrate salt) is raised to 565^{0}C and stored in tanks for later use to generate electricity (up to 3 hrs after sundown). This system is an integrated power station utilizing fossil fuels as well so it can run continuously. Other pilot plants proving successful use a cluster of parabolic dishes to focus the energy to a special sterling engine. The entire system is mounted from a single tower and is designed this way to avoid the difficulties of the construction of a single large dish. Single pilot plants of 25 kW have been in service for some time and 10 plants to the acre is soon envisaged.


Figure 2.5: Heliostat (solar two)

2.2.3.3. Parabolic Trough

Also known as a line focus type collector; the sun's rays are focused to a central line or focal line along the trough. This "line" could be a "collector pipe" which could transfer the energy away to produce some "work". The "collector pipe" temperature is also high enough to cause water to vaporize to steam, so this could be used as a continuous "flash" boiler to drive a turbine or steam engine if scaled correctly. Solar power plants use parabolic troughs to make super heated steam and generate electricity because their fabrication and tracking equipment is less expensive than the dish.

This system could also be used to form an intermittent absorption refrigeration system if the pipe contained ammonia, it would boil off the ammonia with the condensate used to provide cooling in an evaporation box. With a bit more work a continuous cycle absorption refrigerator may be possible, (or possibly a heat exchange system could drive an existing gas fridge.) It could be used for air conditioning, or passive heating, desalination plants, water de-mineralization or purification. Solar trough systems as big as 80MW are in operation with a large number of troughs aligned "north-south" to track the sun. These are hybrid plants that also use natural gas etc. to enable continuous operation through the night. The solar concentrating factor of a parabolic trough is relatively low (10 – 100) depending on its size when compared to the other two types; they give concentration only in one dimension, so that the concentration factor is less than for a parabolic dish.

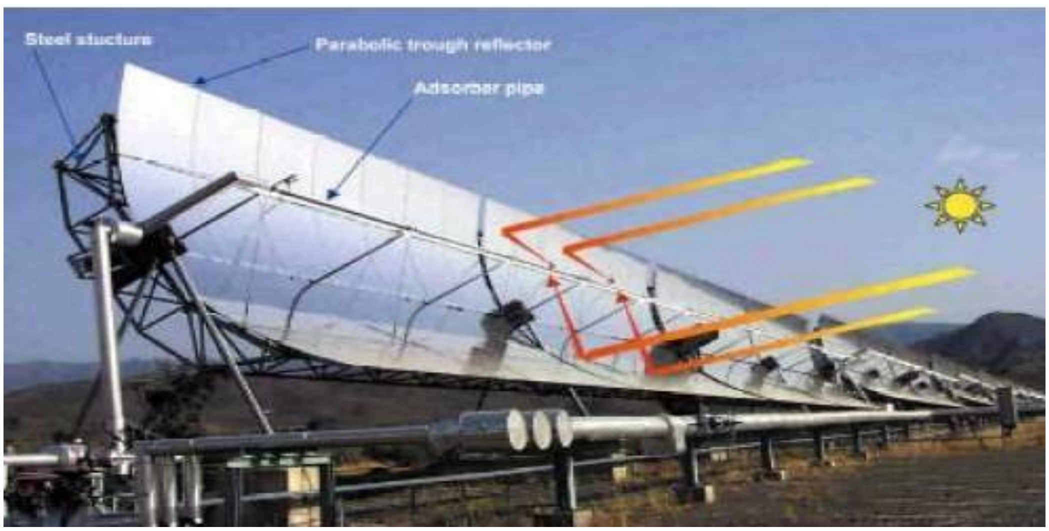


Figure 2.6: Parabolic trough SCA located at a solar research test facility in Spain
(Source: Plataforma Solar de Almeria)

The Saguaro Solar Generating Station north of Tucson, is the first solar thermal parabolic trough power plant built in The US; has a capacity of 1MW compared to 395MW in natural gas fired generating capacity at same site. Broke ground March 24, 2004 and started generating power December 2005.

Figure 2.7: Trough field located at Saguaro Power station in USA

2.3. Solar collector by MIT students

On Jan 28 2008, a team led by MIT students successfully tested a prototype of what may be the most cost-efficient solar power system in the world, as one team member believes has the potential to revolutionize global energy production.

The construction used can be likened to that of the satellite dishes used for services such as **Sky**; and can be called a parabolic collector. The difference being that it is a 12-foot wide dish consisting of an aluminium frame and rows of mirrors making up the surface. The mirrors focus the sunlight by a factor of 1,000 to a single point, therefore creating an immense amount of heat that can then be used for power generation or to melt a bar of steel.

Figure 2.9: Parabolic solar collector by MIT students (Source: MIT news)

Attached to the end of a 12-foot-long aluminum tube rising from the center of the dish is a black-painted coil of tubing that has water running through it; when the dish is pointing directly at the sun; the water in the coil flashes immediately into steam. They could be set up in huge arrays to provide steam for industrial processing, or for heating or cooling buildings, as well as to hook up to steam turbines and generate electricity. The team, led by Ahrens, also includes Micah Sze (Sloan MBA '08), UC Berkeley graduate and Broad Institute engineer Eva Markiewicz, Olin College student Matt Ritter and MIT materials science student Anna Bershteyn; with help from other students over the course of the semester. (David Chandler, 2008)

2.4. Parabolic solar concentrator for industrial heating created by Prof. Ajay Chandak

Figure 2.10: Parabolic solar concentrator by Prof. Ajay Chandak

Features of the system are:

i. Multiple reflectors with square shape in plan.
ii. Compact design as the shape is switched over to square than round.
iii. 100% aperture area available round the year. (Established Scheffler technology gives approximately 60% average aperture area.)
iv. Single axis fixed speed daily automatic tracking eliminates need of sensors and complicated hardware. Tracking system is easy to operate and maintain. Seasonal tracking is manual to be set once in 3-4 days.
v. Photograph shows two reflectors of $6.25m^2$ each delivering 2000 to 2500 Watts per reflector. Trials on higher sizes of $10m^2$ and $15m^2$ square and rectangular dishes are to be conducted before standardization.
vi. Expected cost of this system installation after commercialization is around Rs. 15000/- per kW installation with payback period of less than 30 months without subsidies. This is very comfortable for Industries.
vii. Performance: For air working temp. of 250° C is comfortably achieved. Max. temp. attained for air is about 400° C. Thermic fluid can be comfortably used with second stage heat exchanger for steam generation.

2.5. Solar systems installed in Nigeria

Table 2.1. Solar Thermal systems installed in Nigeria(Source: Sokoto Energy Research centre)

S/N	Type of Project	Location & Date	Size of Project	Sponsor
1	Multi-booster Forage solar Dryer	NAPRI (Zaria) 1996	2 tonne/day	Energy Commission
2	Multi-booster Forage solar Dryer	New-Bussa and Yauri, 1997	1 tonne/day	Energy Commission
3	Solar water Heater	UDUTH (sokoto) 1997	1000 litres	Energy Commission

Figure 2.11.Community based solar water heater by SERC in Sokoto state

2.6. Advantages of solar heating

The following are reasons why solar heating has been used by people

i. **Solar heating saves money and time**

- Sunshine is free. Solar heating saves precious fuel for evenings, cloudy days and cold weather.
- System can be left for continuous heating without checking
- A solar heater is easy to make from a variety of materials.

ii. **Solar heaters are safe, healthy and convenient for cooking**

- There is no fire to cause burns or blow out of control.
- There is no smoke to either injure the eyes or cause lung problems.
- Most solar cookers cook at 82-121ºC (180-250ºF), ideal for retaining nutrients, moisture and flavor and not burning foods. Wood and gas fire temperatures, by contrast, exceed 260ºC (500ºF).
- You can bake, boil and lightly fry foods in their own juices. Meats get very tender.

iii. **Solar heaters help air quality**

- Burning traditional fuels such as wood and gas pollutes the air and contributes to global warming. Solar heaters provide a pollution-free alternative.

2.7. Why solar tracking?

Outside the earth's atmosphere, at any given point space, the energy given off by the sun (Insolation) is nearly constant. On earth, however, that situation changes as a result:

- The earth changing position in space: This makes some parts of the earth to be nearer to the sun on average over the period of a day; from hour to hour, day to day, and year to year. This is the reason for seasons, night and day.
- The earth rotation upon its axis: this makes the earth slightly inclined in relation to the sun. As the earth rotates at a constant speed, there will be certain points in the earth's orbit when the

sun shines for longer on a certain part of the earth.

- The earth's atmosphere (gases, clouds, and dust): The gases in the atmosphere remain relatively stable but due to pollution of the air in recent years due to a phenomenon known as global dimming, particulate matter resulting from fossil fuels, prevents a small fraction of the sun's energy reaching the earth. Clouds are largely transient, and pass from place to place casting shadows on the earth.

Therefore we need to move the solar device to account for the change in the sun's position so as to harness energy efficiently (Gavin D.J. Harper, 2007).

2.8. Losses in heating

Heat losses while solar heating fall into two main categories:

- ➢ Reflective losses i.e. the collector reflecting away some of the radiation supposed to be absorbed by it
- ➢ Absorption Losses i.e. the reflector absorbing part of the solar radiation incident on it.

2.9. Modes of heat transfer

Solar heat is transferred into the food by three mechanisms.

i) By radiation through direct solar rays, that is sunlight striking the heated material.

ii) By convection, that is by the hot air surrounding the heated material inside the chamber.

iii) By conduction; heat is conducted from the tray upon which the material rests.

If the tray is a heavy metal conductor such as steel or aluminum the sun's rays will heat the tray and conduct the heat under the material. All three mechanisms combine to make the heating process very efficient.

3. Methodology

The objective is to use a mould pattern to cast the dish form. This has to have an accurate shape and no imperfections upon the surface. A steel former with a top and bottom axle is used to "form" the concrete mould to the shape of your parabola. Concrete is readily workable to a smooth surface and it's relatively cheap, and any imperfections can be repaired with filler afterwards, (It is easier to fill than grind off.) The various materials to design components were locally sourced and manufactured by molding and fabrication as the need demanded.

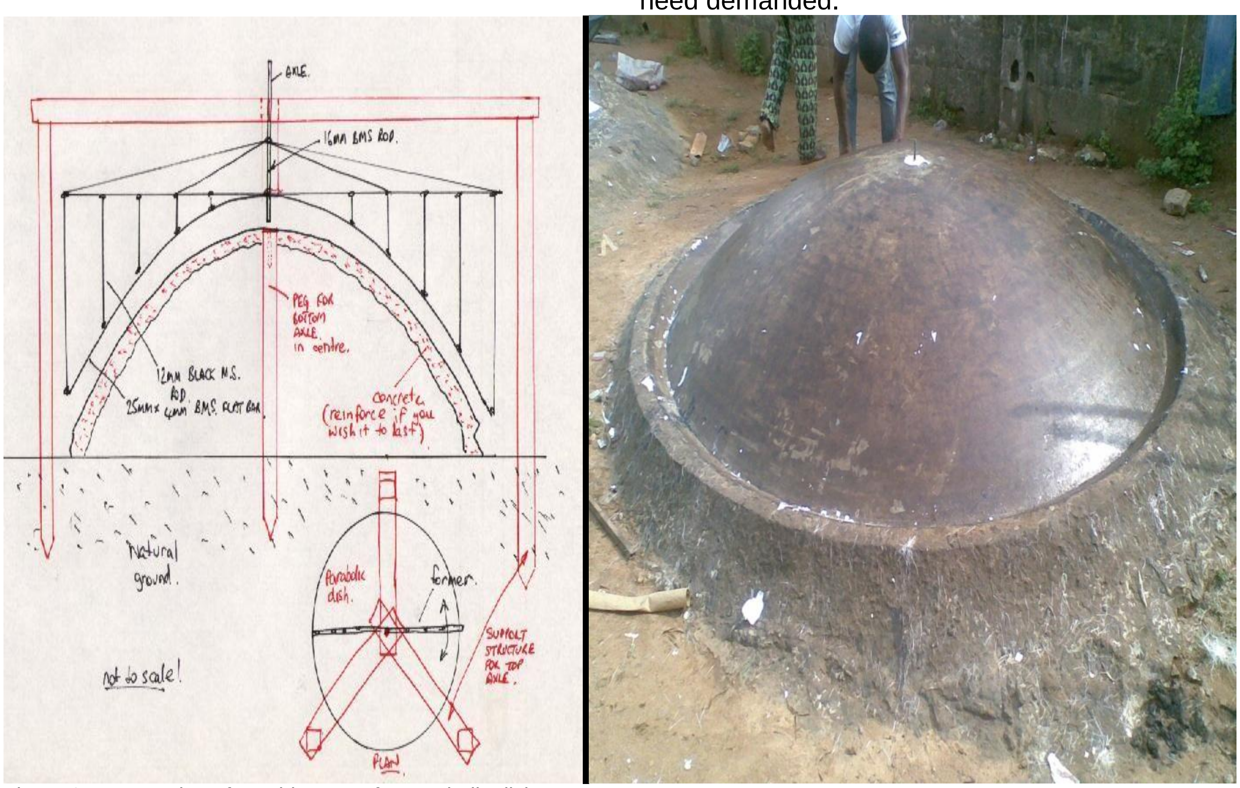


Figure 3.1: Formation of mould pattern for parabolic dish

Once the mould is finished the dish can be cast from it with whatever you wish to use, - i.e. more concrete, fiberglass, reinforced fiber polymer, clay, paper mache etc. If you wish to use the dish as a microwave antenna then construction should be made with fiberglass and "bird" wire netting or "aluminium foil" should be incorporated within the layers of fiber-glassing; or perhaps coat the parabolic surface with a heavy copper based paint (many coats) This will provide the necessary reflective surface for the microwave energy. If using fiber-glassing, a "chrome" paint, or highly silvered paint could be applied before applying the finish top clear gel coat, this may provide a satisfactory mirrored surface. Shinny aluminium foil could also be "laid and rolled" before the top gel coat and might provide a good reflector. Thin polished stainless steel sections cut to fit in together could be laid onto the surface and held into position from the rim and centre, and would provide a good mirrored surface for any use. Silicon sealant applied sparingly might "hold" any stubborn pieces down.

3.1. Materials

- Four packs of aluminium foil (each 8m long)
- Fiber (mat pattern)
- Catalyst (colorless)
- Accelerator (purple)
- Polyester resin
- Metals preferably iron (for the dish stand, dish frame, and pot holder).
- Pot (with a painted black); Dark surfaces get very hot in sunlight, whereas light surfaces don't. Heat is best transferred in dark, shallow, thin metal container with dark, tight-fitting lids to hold in heat and moisture.

3.2. Parabolic dish pattern profile

The parabolic dish to be designed is assumed to have a focal length of 65cm.Using this focal length and variable of x, the y variables can be determined, so that the profile can be traced out.
Using the formula: $y = x^2/4f$ (where f = 65cm and x = 20, 40, 60, 80 ……..cm)

X	Y
20	1.538
40	6.154
60	13.846
80	24.615
100	38.463
120	55.385
140	75.385
160	98.462
180	124.615
200	153.846

3.3. The moulding of the dish

The parabolic dish to be used in the design is a composite (fiber reinforced polymer) made up of fiber and pure polyester resin. Steps involved in the dish moulding process:

1. Clean the parabolic concrete moulded pattern surface, washing with soap and water.
2. Apply pure polyester resin to the surface of the mould to act as releasing agent for easy removal of the moulded dish from the pattern.
3. Use wet foam to line the pattern surface with aluminum foil, ensure that the more reflective part of the aluminum foil be put to the surface of the mould pattern, for better reflectivity of the surface.
4. Use polyester resin to attach the lapping aluminum foils together.
5. The entire surface of the mould pattern should now be covered with aluminum foil.
6. Next; cover the surface with fiber, just laying it over the surface of the aluminum.
7. Pour the polyester resin into a bowl, after which you add the accelerator, then catalyst (note: do not mix both catalyst and accelerator directly to avoid producing smoke or burning the fiber); this ensures forming of the polymer around the fiber, acting as hardener to the resin, which is characteristic of the polymer.
8. Leave for about 2 hours for the forming together of the fiber and polymer.
9. Place the Iron frame structure that has been fabricated in the workshop for the support of the composite structure.
10. Lay fiber on the iron frame place on the moulded structure, then apply the (pure polyester resin + accelerator +catalyst) combination to the fiber and frame structure.
11. Then leave for a day (24hours) for final setting.
12. After final setting, the parabolic dish is removed then re-foiled using shinny aluminium foil to act as a reflector.

The major problem faced during the production of the parabolic dish was the error associated with moulding and aligning the parabolic dish shape.

4. **Result and discussion**

The moulded dish diameter is 2.46m or 246cm (i.e. x = 123cm); with a height of 58.188cm.

While testing the device the absorber's position for optimal performance is at 60cm which is close to the theoretically value of 65cm.

Four (4) tests were carried out in the month of March to determine the temperature rise within a time frame, on the average the water placed within the collector increased from a temperature of 27-85ºC within 20 minutes.

4.1. Calculation

Data

Area of parabolic dish = 2/3 bh = 2/3 x 2.46 x 0.5818= $\underline{0.95m^2}$

Area of absorber = $\underline{0.0173m^2}$

Volume of water used= 75cL = $0.00075m^3$ = $750cm^3$

Density of water is approximated to be $1g/cm^3$

Specific heat capacity of water (c_w)= $4.186J/g^0C$

Time of heat transfer(t)= 20min = 20 x 60 = 1200sec

Mass (m) = Density X Volume = 750 X 1 = 750g

i. Quantity of heat absorbed (Q) = $m \times c_w \times (T_2 - T_1)$ = 750 x 4.186 x (85-27) = 182091J or 182.09KJ
ii. Power/Heat transfer rate = Q/t =182091/1200= 151.74W
iii. Concentration factor = area of reflector/ area of absorber = 0.95/0.0173 = 54.9
iv. *Since* $C_{ideal} = (\sin\theta)^{-2}$ for a 3-D concentrator (point – focus)
    $54.9 = (\sin\theta)^{-2}$
    Therefore acceptance angle (θ) = arc sin (0.13496) = $\underline{7.76^0}$

With a Concentration factor of 55 and with a power rating of 151.74W the designed dish can be used as follows:

i. For less than 100^oC: heated water can be used for domestic purposes and swimming pools, heating of buildings, and evaporative systems such as distillation and dryers;
ii. For less than 150^oC: air conditioning, and heating of water, oil, or air for industrial use.

4.2. Performance prediction

The test location for the parabolic dish solar heater is Covenant University situated in Ota (alternatively spelled Otta) a town in Ogun State, Nigeria, with an estimate of 163,783 residents living in or around it. Ota has the third largest concentration of industries in Nigeria. Ota in Ogun state is located on latitude 7^o 57'N and longitude 4^o 47'E.

Ideally, the data required to predict the solar input are several years of measurements of irradiance on the proposed collector plane. These are very rarely available, so the required (statistical) measures have to be estimated from meteorological data available either (i) from the site, or (ii) (more likely) from some 'nearby' site having similar irradiance, or (iii) (most likely) from an official solar atlas or database. All such data have systematic error and uncertainty, and natural climatic variability. Since there is no meteorological data for Ota having being to NIMET (Nigerian metrological Center), and there are no readily available solar radiation measuring instruments in this institution metrological data for a nearby site having similar solar irradiance shall be used. meteorological data for Abeokuta which is a located in Ogun state would be used.

Metrological data are available for Abeokuta and Ikeja; Abeokuta the capital of Ogun state is located on latitude $7^.15^0$N and Longitude $3^.35^0$E while Ikeja which is also close to ota is located on latitude 6.583^0N Longitude 3.333^0E. Due to the closeness in the latitude and longitudes of Otta with those of abeokuta the meteorogical data of abeokuta shall be used.

Table 4.1.Showing monthly mean daily global solar radiation on a horizontal surface (KWh/m^2 -day) for Abeokuta station in Ogun state, Nigeria

Month	**Solar radiation (KWh/m^2 -day)**
January	4.107
February	4.764
March	4.742
April	4.951
May	4.703
June	3.878
July	3.51
August	3.438
September	3.952
October	4.423
November	4.449
December	4.114
Annual mean	4.253

Based on the solar radiation data obtained, the operational power and capacity of the solar dish for each given month can be approximated, for the same period of time (20 minutes).

Table 4.2.Showing monthly mean daily global solar radiation on a horizontal surface (KWh/m^2 -day) and power rating of solar dish for Abeokuta station in Ogun state, Nigeria

Month	Solar radiation (KWh/m2 -day)	Power (W)
January	4.107	131.42
February	4.764	152.44
March	4.742	151.74
April	4.951	158.43
May	4.703	150.49
June	3.878	124.1
July	3.51	112.32
August	3.438	110.01
September	3.952	126.46
October	4.423	141.53
November	4.449	142.36
December	4.114	131.64
Annual mean	4.253	136.09

4.3. Limitation of the project

While carrying out the test on the parabolic solar dish the following drawbacks which we encountered include:

- Due to the intermittency of sunlight, the expected time for heating can vary.
- Less than perfect reflector surface reflectivity i.e. the reflectivity of the aluminium foil used is less than 1, hence there would be losses especially by surface absorption.
- Problem of Tracking the sun's position and angle of incidence.
- Drawbacks such as burns, alignment of collector, glare and reflections from surface
- Heat Losses associated with the heated water by convection and radiation i.e. the water contained in the absorber would lose part of its heat simultaneous to the atmosphere as it is being heated.

5. **Conclusion and recommendation**

5.1. Conclusion

The task of designing and constructing a parabolic solar dish that is efficient, functional and economically viable requires good technical knowledge of how the various components work. Also, material selection for optimal performance at lowest possible cost, engineering principles involving heat transfer, the concept of solar energy and how it can be effectively harnessed were used to design and produce this parabolic solar heater.

Application of this developed technology to provide energy for heating would supplement the heat energy provision for domestic uses otherwise derived from burning of fossil fuel energy resources and hydro-plants.

5.2 Recommendation

1. The heated water with the use of a properly designed piping system can be used to take heated water into buildings for various purposes: because most water heating systems use flat collectors (less than 70^{o}C) but this system provides a higher temperature above 80^{o}C.
2. This system can be used in heating air and water; dwellings in cold climates need heated air for comfort, and in all countries hot water is used for washing and other domestic purposes.

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