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Engineering, design and fabrication of a solar cooker with parabolic concentrator for heating, drying and cooking purposes

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ABSTRACT

Indian subcontinent is blessed with ample amount of sunlight almost all through the year. Roughly 80% of all seasons are sunny of which 50% is dry and hottest. There is urgent need of switching over to a perennial source of energy reserve as a powerful alternative so as to replace all the fastly depleting fossil fuels. There is much interest in non conventional energy nowadays so as to tap energy from unassuming but promising quarters such as Solar, Wind and Tidal energy. Of which, tapping the heat and infra-red rays from the sun using air and water as appropriate mediums, separately and together as a whole is the most easiest and versatile way of energy capture. In order to tap this abundant energy we require an efficient design of a solar concentrator which heats up the ambient in the quickest pace. A cost effective solar concentrator is made with locally available raw materials which is efficient enough to make water reach steam point and air reach its hottest phase. A thorough dealing with a span of six months observation on the working of the solar cooker is presented in detail.

Keywords: *Solar energy, solar concentrator, solar water heater, solar air heater, NCE*

INTRODUCTION

Solar Energy is the resultant outcome of thermonuclear reactions of fusion from "hydrogen" into "helium" taking place in the sun. These thermonuclear reactions release huge energy and radiate the energy to space continuously. This kind of energy which is continuous and perennial is available as solar energy. The average intensity of solar radiation on the earth orbit is 1367kW/m^2, and the earth's equatorial circumference is 40,000km, so it can be worked out that the energy the earth obtains is up to 173,000TW.

The energy on earth, including wind energy, hydropower, ocean thermal energy, wave energy, bioenergy and some tidal energy all come from the sun. Even the fossil fuels on earth (such as coal, petroleum, natural gas, etc.) are at bottom the solar energy that has kept in storage since time immemorial, so the solar energy in a broad sense covers a vast scope, and the narrow-sensed solar energy is confined to the direct transformation of solar radiation from sunlight to heat, electricity and chemical energy. The solar energy is a primary energy source, and it is also renewable energy. It is rich in resources without transport, which is both free for use and non-contaminative to the environment.

There is a long history for humans to use solar energy. In the period of Warring States, some 2,000 years ago, Chinese people knew how to use a four-side steel mirror to focus the sunlight for making a fire, and they used solar energy to dry agricultural products. In modern times, the use of solar energy becomes increasingly widespread, which includes solar thermal utilization, solar photovoltaic utilization and solar photochemical utilization etc., Solar power is the conversion of sunlight into electricity. Sunlight can be converted directly into electricity using photo-voltaics (PV), or indirectly with concentrated solar power (CSP), which normally focuses the sun's energy to boil water which is then used to provide power. Other technologies also exist, such as Stirling engine dishes which use a Stirling Cycle engine to power a generator. Photovoltaics were initially used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array. Concentrating Solar Power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. [1]

Heat Principles

The basic purpose of a solar box cooker is to heat things up - cook food, purify water, and sterilize instruments - to mention a few. A solar box cooks because the interior of the box is heated by the energy of the sun. Sunlight, both direct and reflected, enters the solar box through the glass or plastic top. (Fig.1) It turns to heat energy when it is absorbed by the dark absorber plate and cooking pots. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. Temperatures sufficient for cooking food and pasteurizing water are easily achieved. Given two boxes that have the same heat retention capabilities, the one that has more gain, from stronger sunlight or additional sunlight via a reflector, will be hotter inside. [2] Given two boxes that have equal heat gain, the one that has more heat retention capabilities - better insulated walls, bottom, and top - will reach a higher interior temperature. The following heating principles will be considered first:

A. Heat gain
B. Heat loss
C. Heat storage:

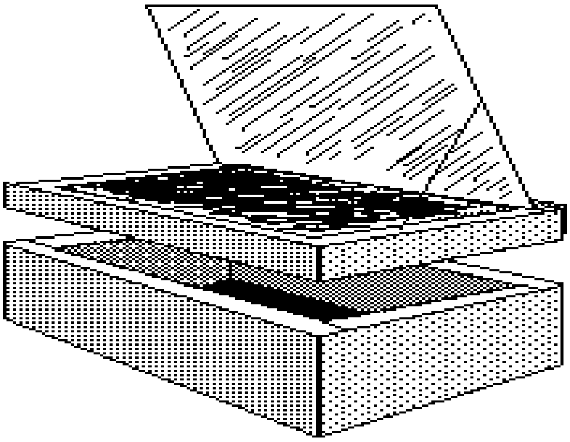

Figure 1. Solar box cooker with cover, window, and reflector

Heat gain by Greenhouse effect: This effect results in the heating of enclosed spaces into which the sun shines through a transparent material such as glass or plastic. Visible light easily passes through the glass and is absorbed and reflected by materials within the enclosed space. The light energy that is absorbed by dark pots and the dark absorber plate underneath the pots is converted into longer wavelength heat energy and radiates from the interior materials. Most of this radiant energy, because it is of a longer wavelength, cannot pass back out through the glass and is therefore trapped within the enclosed space. (Fig.2)

The reflected light is either absorbed by other materials within the space or, because it doesn't change wavelength, passes back out through the glass. Critical to solar cooker performance, the heat that is collected by the dark metal absorber plate and pots is conducted through those materials to heat and cook the food.

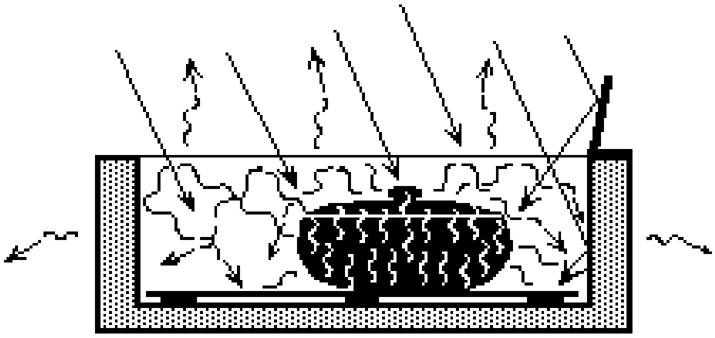

Figure 2. The greenhouse effect

Heat gain by Glass orientation: The more directly the glass faces the sun, the greater the solar heat gain. Although the glass is the same size on box 1 and box 2, more sun shines through the glass on box 2 because it faces the sun more directly. Note that box 2 also has more wall area through which to lose heat. (fig.3)

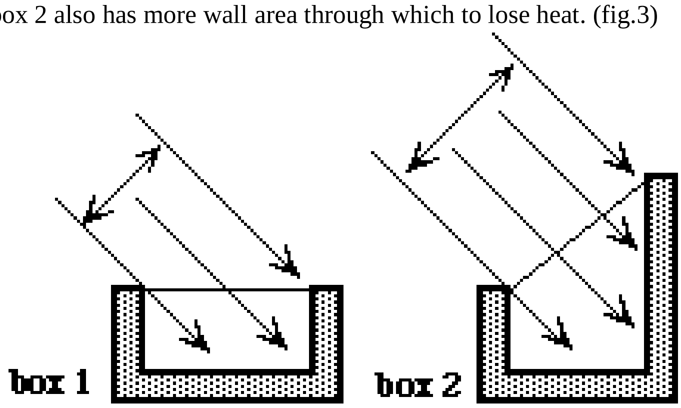

Figure 3. Glass orientation

Additional Heat Gain by Reflectors: Single or multiple reflectors bounce additional sunlight through the glass and into the solar box. This additional input of solar energy results in higher cooker temperatures. (Fig.4)

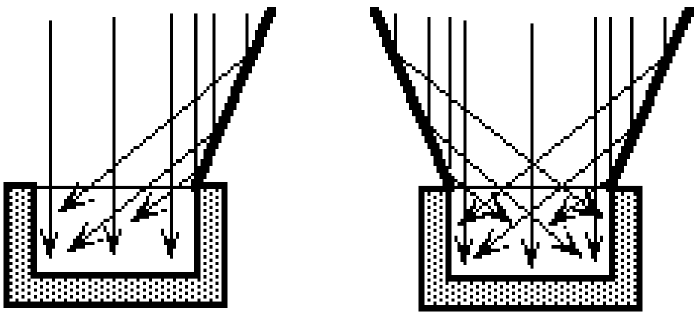

Figure 4. Reflectors for additional solar gain

Heat loss

The Second Law of Thermodynamics states that heat always travels from hot to cold. Heat within a solar box cooker is lost in three fundamental ways: Conduction, Radiation, and Convection

Heat Loss by Conduction:
The handle of a metal pan on a stove or fire becomes hot through the transfer of heat from the fire through the materials of the pan, to the materials of the handle. In the same way, heat within a solar box is lost when it travels through the molecules of tin foil, glass, cardboard, air, and insulation, to the air outside of the box. The solar heated absorber plate conducts heat to the bottoms of the pots. To prevent loss of this heat via conduction through the bottom of the cooker, the absorber plate is raised from the bottom using small insulating spacers as in figure 5.

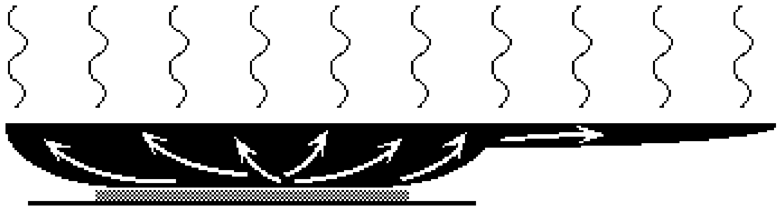

Figure 5. Heat conducted through the pan to handle

Heat loss by Radiation: Things that are warm or hot -- fires, stoves, or pots and food within a solar box cooker -- give off heat waves, or radiate heat to their surroundings. These heat waves are radiated from warm objects through air or space. Most of the radiant heat given off by the warm pots within a solar box is reflected from the foil and glass back to the pots and bottom tray. Although the transparent glazings do trap most of the radiant heat, some does escape directly through the glazing. Glass traps radiant heat better than most plastics. (Fig.6)

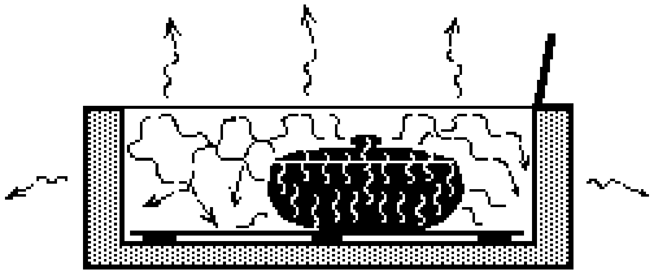

Figure 6. Heat radiates from warm cookware.

Heat loss by Convection: Molecules of air move in and out of the box through cracks. They convect. Heated air molecules within a solar box escape, primarily through the cracks around the top lid, a side "oven door" opening, or construction imperfections. Cooler air from outside the box also enters through these openings. (Fig.7)

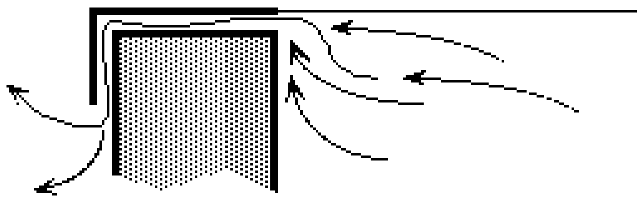

Figure 7. Heated air may escape through cracks.

Heat loss by Heat storage:
As the density and weight of the materials within the insulated shell of a solar box cooker increase, the capacity of the box to hold heat increases. The interior of a box including heavy materials such as rocks, bricks, heavy pans, water, or heavy foods will take longer to heat up because of this additional heat storage capacity. The incoming energy is stored as heat in these heavy materials, slowing down the heating of the air in the box. These dense materials, charged with heat, will radiate that heat within the box, keeping it warm for a longer period at the day's end. (Fig.8)

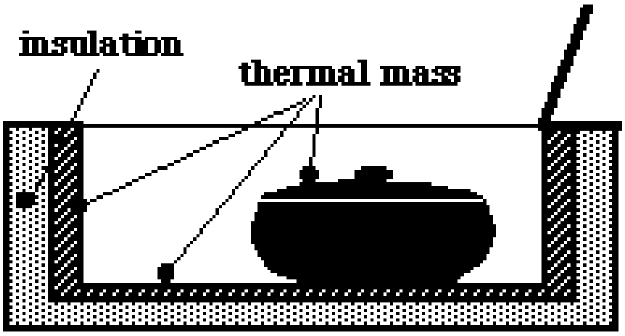

Figure 8. Thermal mass inside of the solar box.

Material Requirements:

There are three types of materials that are typically used in the construction of solar box cookers. A property that must be considered in the selection of materials is moisture resistance. [3]

A. Structural material, B. Insulation, C. Transparent material, D. Moisture resistance

Structural material

Structural materials are necessary so that the box will have and retain a given shape and form, and be durable over time. Structural materials include cardboard, wood, plywood, masonite, bamboo, metal, cement, bricks, stone, glass, fiberglass, woven reeds, rattan, plastic, papier mache, clay, rammed earth, metals, tree bark, cloth stiffened with glue or other material. Many materials that perform well structurally are too dense to be good insulators.[4] To provide both structural integrity and good insulation qualities, it is usually necessary to use separate structural and insulating materials. (Fig.9)

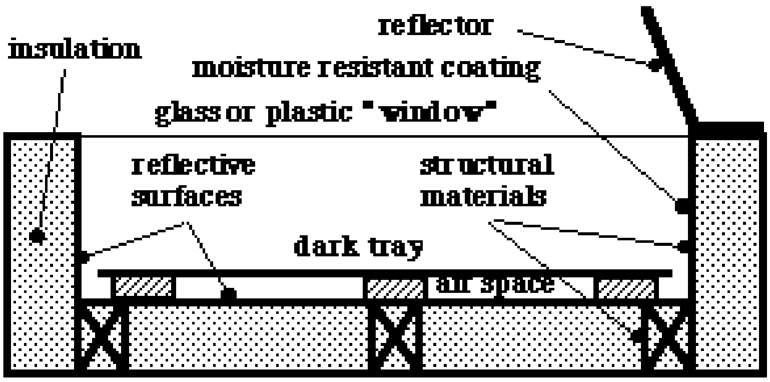

Figure 9: Materials: structural, insulation, transparent, and moisture resistant.

Insulation

In order for the box to reach interior temperatures high enough for cooking, the walls and the bottom of the box must have good insulation (heat retention) value. Good insulating materials include: aluminum foil (radiant reflector), feathers (down feathers are best), spun fiberglass, rockwool, cellulose, rice hulls, wool, straw, and crumpled newspaper.

When building a solar cooker, it is important that the insulation materials surround the interior cooking cavity of the solar box on all sides except for the glazed side -- usually the top. Insulating materials should be installed so that they allow minimal conduction of heat from the inner box structural materials to the outer box structural materials. The lower the box heat loss, the higher the cooking temperatures.[5]

Transparent material
At least one surface of the box must be transparent and face the sun to provide for heating via the "greenhouse effect." The most common glazing materials are glass and high temperature plastics such as oven roasting bags. Double glazing using either glass or plastic affects both the heat gain and the heat loss. Depending on the material used, the solar transmittance - heat gain - may be reduced by 5-15%. However, because the heat loss through the glass or plastic is cut in half, the overall solar box performance is increased.

Moisture resistance
Most foods that are cooked in a solar box cooker contain moisture. When water or food is heated in the solar box, a vapor pressure is created, driving the moisture from the inside to the outside of the box. There are several ways that this moisture can travel. It can escape directly through box gaps and cracks or be forced into the box walls and bottom if there is no moisture barrier. If a box is designed with high quality seals and moisture barriers, the water vapor may be retained inside the cooking chamber. In the design of most solar box cookers, it is important that the inner-most surface of the cooker be a good vapor barrier. This barrier will prevent water damage to the insulation and structural materials of the cooker by slowing the migration of water vapor into the walls and bottom of the cooker.

DESIGN, PROPORTION, and OPERATION
Box size
A solar box cooker [6] should be sized in consideration of the following factors:
- The size should allow for the largest amount of food commonly cooked.
- If the box needs to be moved often, it should not be so large that this task is difficult.
- The box design must accommodate the cookware that is available or commonly used.

Solar collection area to box volume ratio
Everything else being equal, the greater the solar collection area of the box relative to the heat loss area of the box, the higher the cooking temperatures will be. Given two boxes that have solar collection areas of equal size and proportion, the one that is of less depth will be hotter because it has less heat loss area.

Solar box cooker proportion
A solar box cooker facing the noon sun should be longer in the east/west dimension to make better use of the reflector over a cooking period of several hours. As the sun travels across the sky, this configuration effects in engulfing a large amount of IR radiations resulting in consistent and stable cooking temperature. With square cookers or ones having the longest dimension north/south, a greater percentage of the early morning and late afternoon sunlight is reflected from the reflector to the ground, missing the box collection area. (Fig.10)

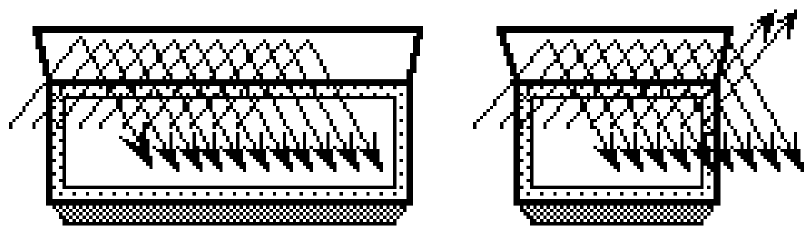

Figure 10: Wider solar boxes catch more of the east and west sunlight.

Reflector
One or more reflectors are employed to bounce additional light into the solar box in order to increase cooking temperatures. Although it is possible to solar cook without reflectors in equatorial when the sun is mostly overhead, reflectors increase cooking performance significantly in temperate regions of the world.

Solar Box Cooker Operation:

One of the beauties of solar box cookers is their ease of operation. For mid-day cooking at 20° N - 20° S latitude, solar box cookers with no reflector need little repositioning to face the sun as it moves across the mid-day sky. The box faces up and the sun is high in the sky for a good part of the day. Boxes with reflectors can be positioned toward the morning or afternoon sun to do the cooking at those times of day. [7] Solar box cookers used with reflectors in the temperate zones do operate at higher temperatures if the box is repositioned to face the sun every hour or two. This adjustment of position becomes less necessary as the east/west dimension of the box increases relative to the north/south orientation. (Fig. 11)

Fig. 11 Solar cooker with a stainless steel vessel for temperature profiling

Fig. 12: Concentrator – top view

Fig. 13 Concentrator - bottom view

Solar radiation falling in enclosed spaces gets collected naturally. But when a metal parabolic collector blackened for maximum quantum efficiency was placed inside the solar cooker, there exists a possibility when by the inclusion of a parabolic concentrator, there could be an increase in efficiency of the infra-red rays collected (Fig. 12, 13, 14). Profiling studies with and without the concentrator were done and a detailed examination of the results were also done. [8]

Fig. 14: Solar Cooker with concentrator (view 1)

SOLAR COOKER PROFILING

The profiling studies were carried out on the internal temperature gradient and ambient of the cooking chamber inside the solar cooker. A thermometer with a maximum calibration of 100˚C was used to record the temperature from morning till evening or till the availability of solar radiation. [9] In the first place the readings were taken with and without the concentrator on many specific occasions namely

1. Clear Day
2. Cloudy day
3. Partially cloudy day

The results were repeated for all the above cases after including the concentrator. It was observed from the graph that the inclusion of the concentrator maximized the total temperature observed by a stable amount.

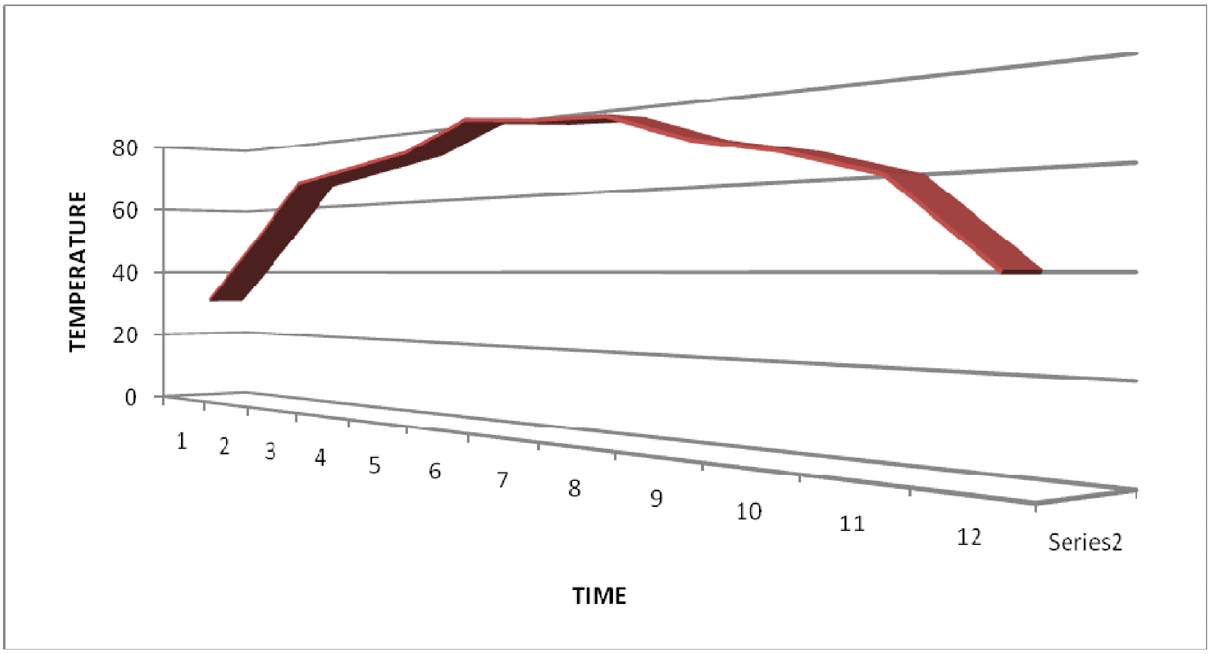

Fig. 15: Solar cooker with concentrator on a Clear day (max 79˚C)

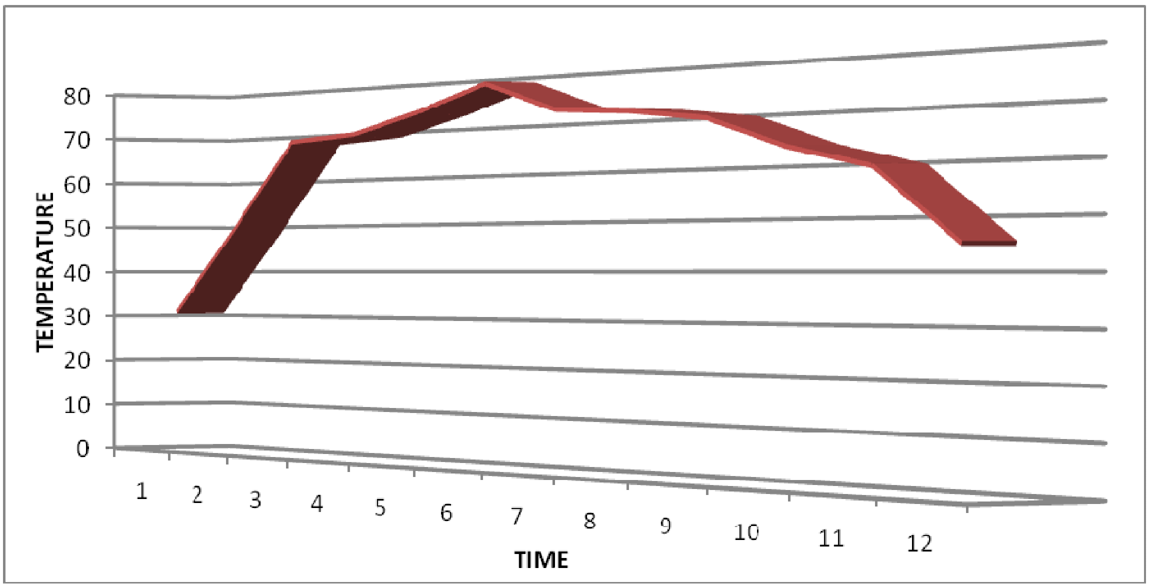

Fig. 16: Cooker with concentrator on a clear day (max 75˚C)

The temperature profile on a clear day with two individual maxima's are shown above. Both clearly indicate that the individual maximum temperature was around 78-80˚C which was at noon and existed for a time period of 1-1hr 30 min. This clearly depicts that maximum efficiency is reached only around noon (Fig. 15, 16)

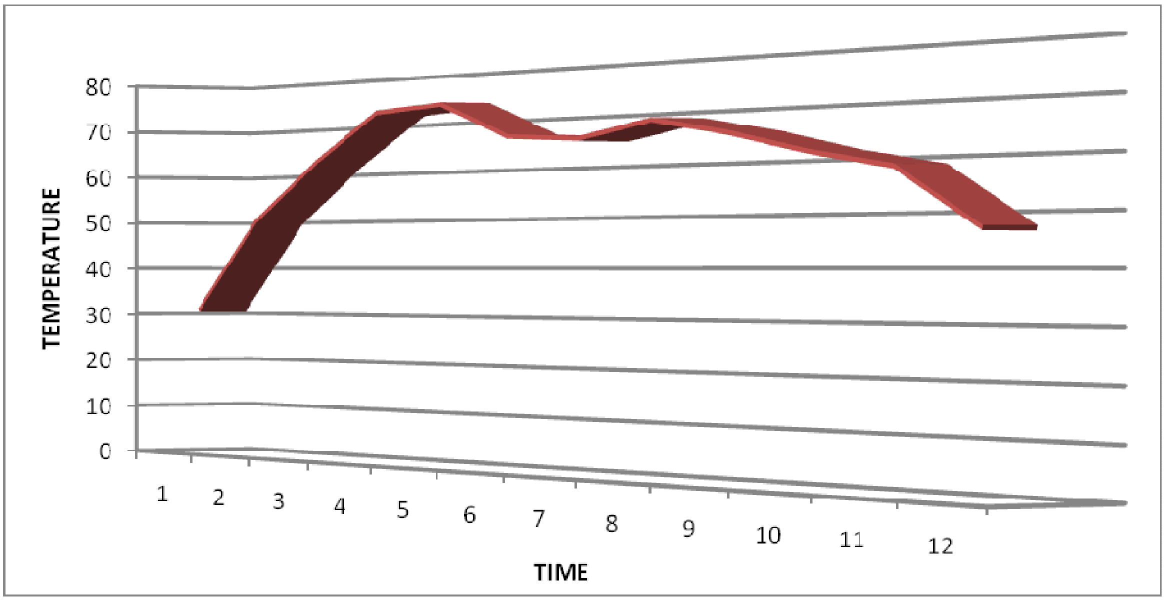

Fig. 17: Cooker with concentrator on a partially cloudy day. (max 72˚C)

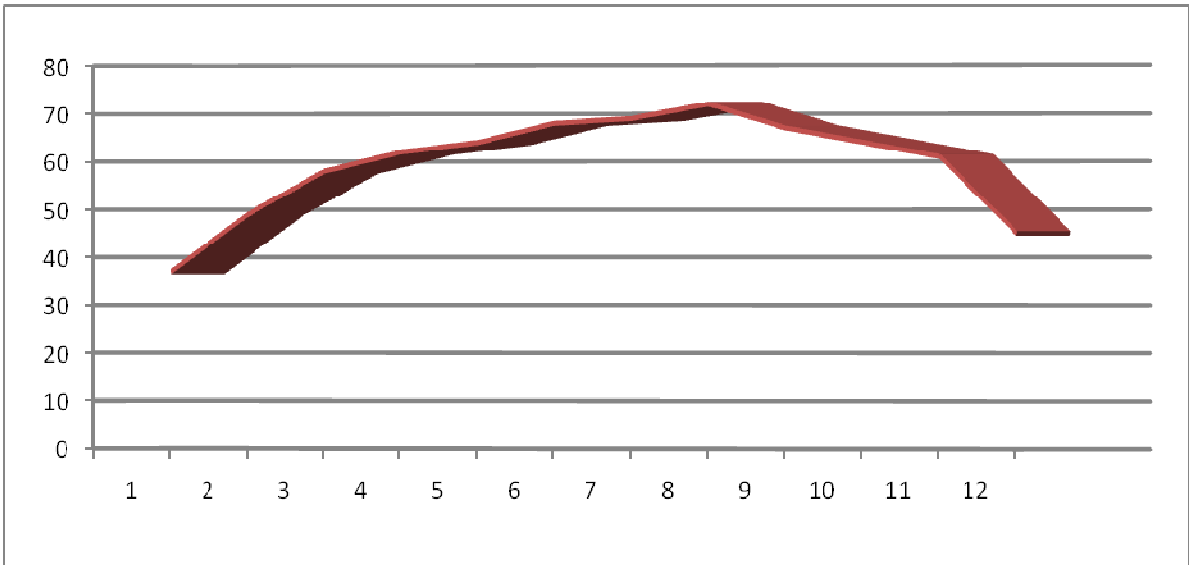

Fig. 18: Partially cloudy day (max 70˚C)

Temperature profiling on a cloudy day depicted that the maximum temperature was identified during the same time, viz., noon time, but there was no visible peak or shoot-up of the temperature which inferred that the stability and entropy of the system was slightly more than the clear day. (Fig. 17, 18) This depicts that temperature retention of the system was more in this case. Maximum temperature was recorded at 70˚C.

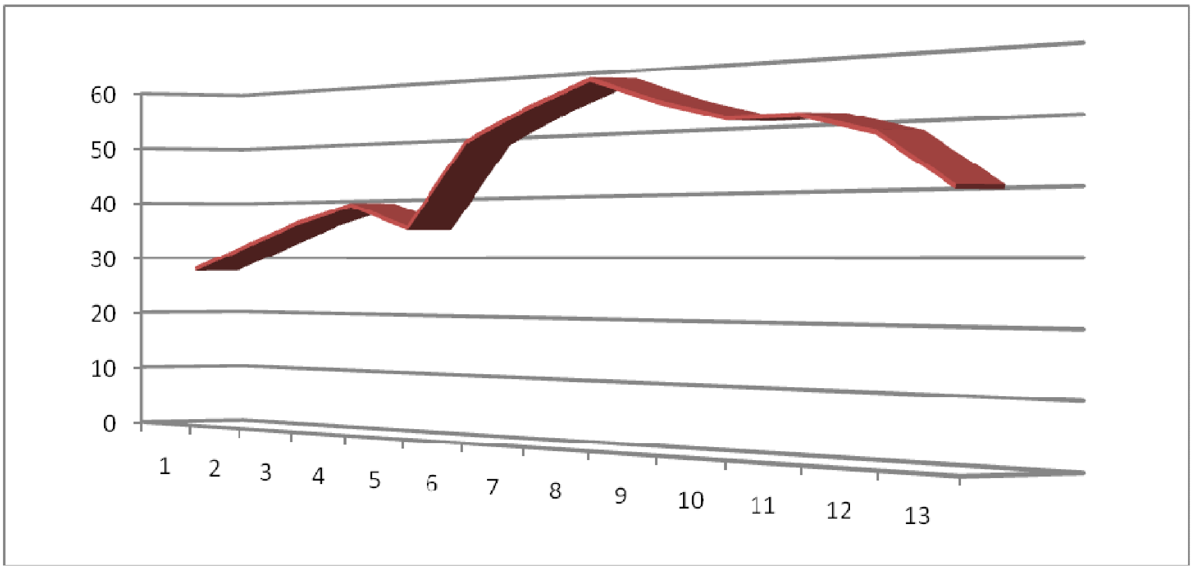

Fig. 19: Temperature graph on a heavily cloudy day (max 59˚C)

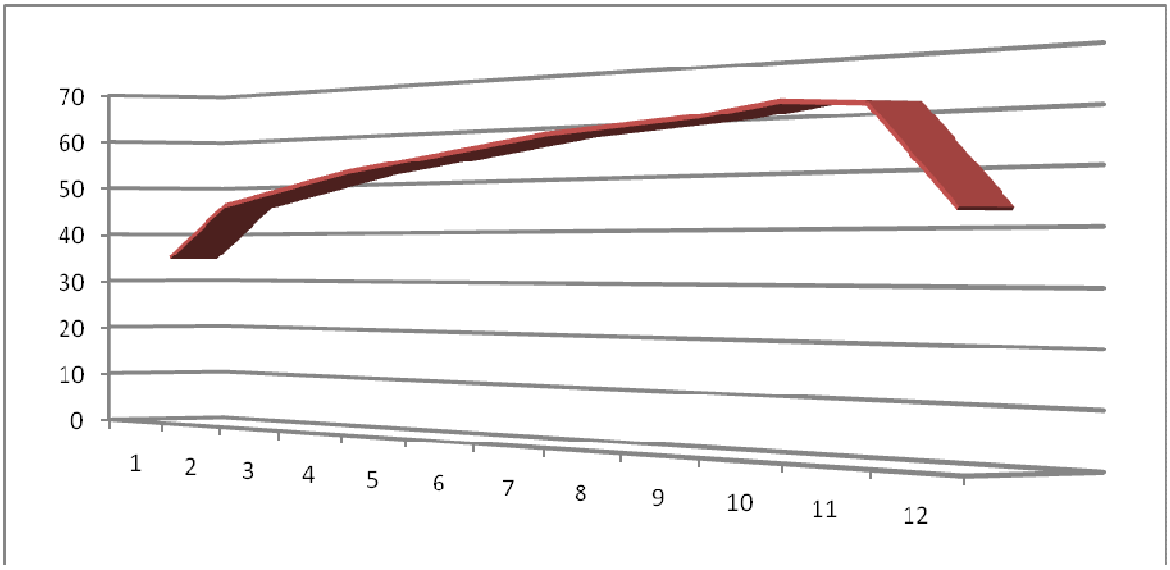

Fig. 20: Cooker Temperature response on a heavily cloudy day (max 64˚C)

Studies on temperature profiling on a heavily clouded day indicated that there was a gradual to very minimal gradual increase in the temperature which was because due to the non-availability of infra-red radiations since due to cloudy nature couple be moisture. The maximum temperature recorded was around 62˚C since there was only a limited amount of infra-red radiations (Fig. 19, 20).

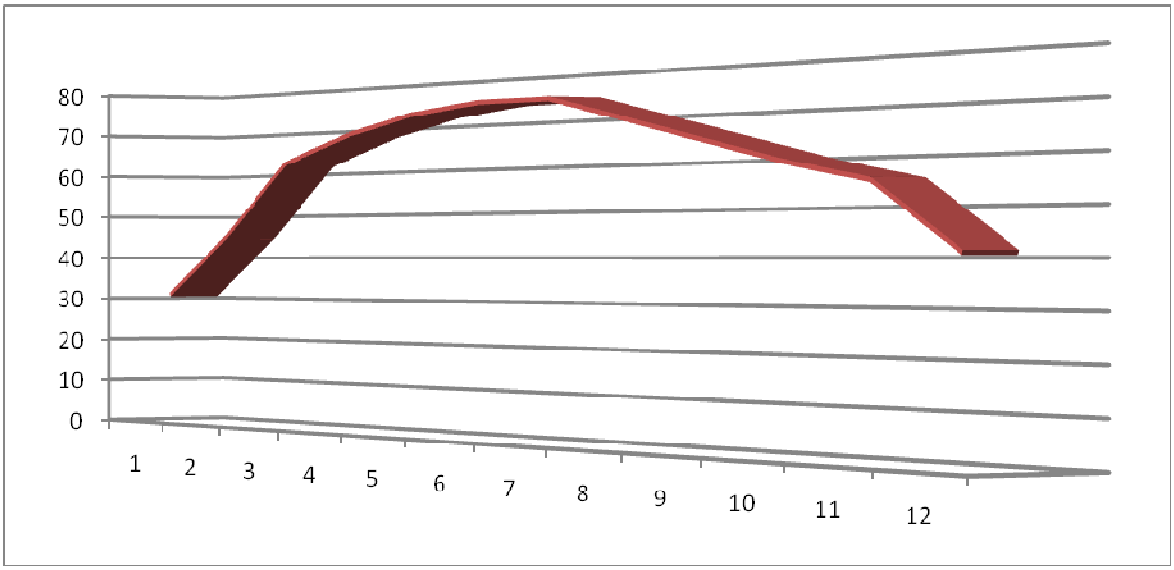

Fig. 21: Cooker temperature response on a partially Clear Day with concentrator (max 74˚C)

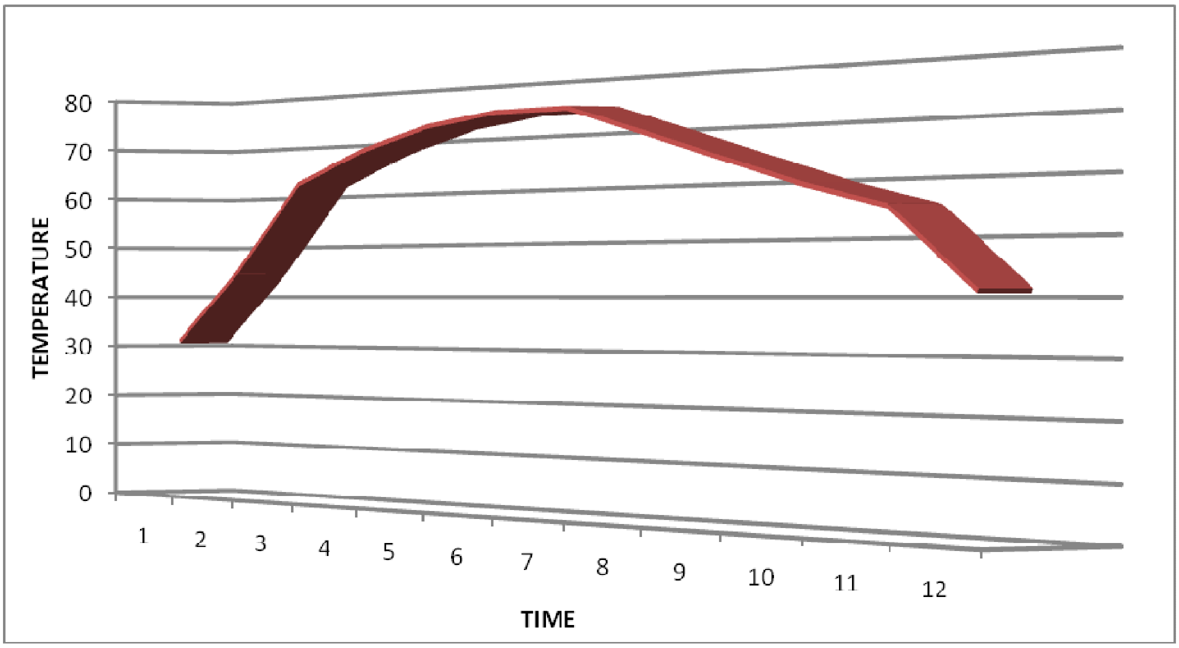

Fig. 22: Temperature profiles on a clear day with concentrator

The same observations were repeated with an aid of a metal parabolic concentrator which was placed inside the solar cooker. The recorded observations at the outset showed a clear, stable and smooth increase without fluctuations. There was a uniformity in the maxima observed which was around 80˚C for a clear day. This was comparatively more than the reading observed without the concentrator. There is a visible increase in the quantum efficiency of the collected radiation which is concentrated and converted into useful form and retained. (Fig. 21, 22)

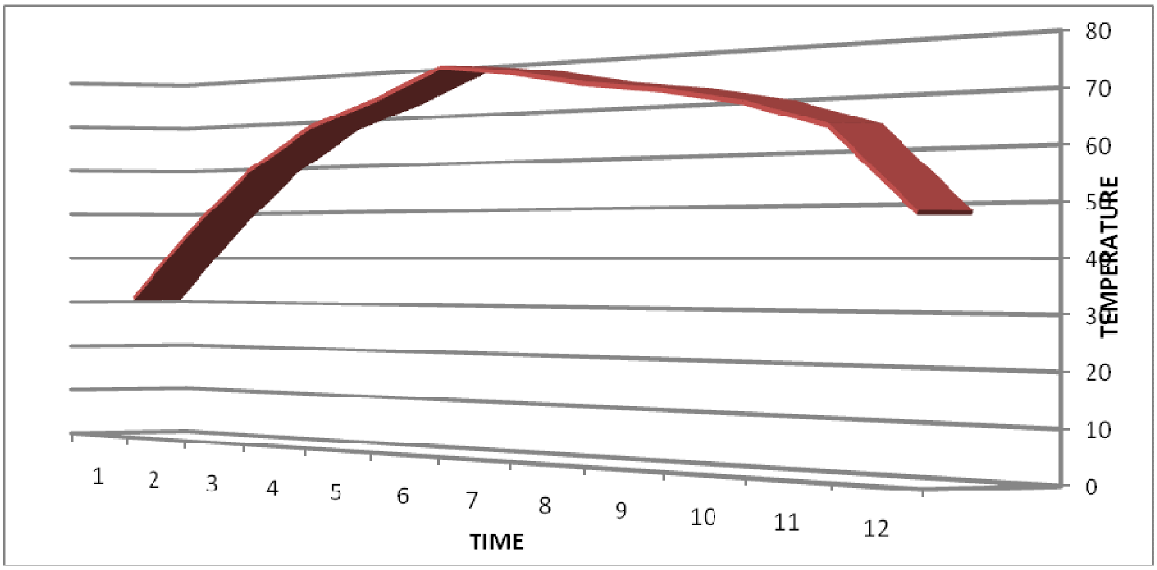

Fig. 23: Temperature profiles on a partially cloudy day with concentrator

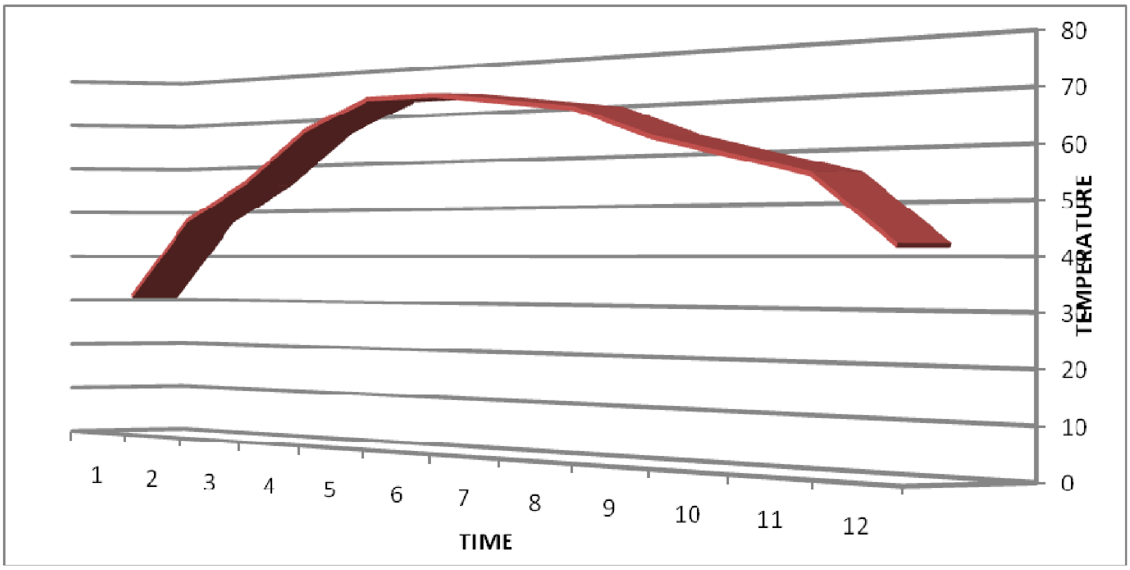

Fig. 24: Temperature profile on a heavily cloudy day with concentrator.

Temperature profiles on partially and heavily clouded days with a concentrator recorded the same uniformity in temperature retention where the retention ratio was more since the concentrator was seen to possibly play a vital part in the absorption and retention of available infra-red radiations (Fig. 23, 24)

RESULTS AND DISCUSSION

A box type solar cooker was designed and developed indigenously using locally available materials. [10] A parabolic solar concentrator was also designed to be included inside the solar cooker which was found to ultimately increase the retention ratio and quantum efficiency of the infra-red radiations collected. The solar cooker was tested for its efficiency with and without the parabolic concentrator whereby the results proved that the parabolic concentrator played a major part in increasing the collection ratio and thereby the ambient temperature inside the solar cooker.

CONCLUSION

1. A Solar cooker was fabricated in accordance to the details available in journals. [11]
2. Temperature Profiling was carried out and graphically represented. [12]
3. A parabolic concentrator was included with its base darkened for maximum absorption.
4. Temperature profiling was carried out with the parabolic concentrator and it was observed that the concentrator maximized the temperature yield of the internal cooking ambient of the solar cooker.[13]

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