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Design and Study of Compound Parabolic Trough Collector Based Solar Air Cooker for Advanced Heat Interception

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***Abstract*:-- In this paper, we have discussed the design of a solar cooker that uses heated air for contact less cooking using a compound parabolic trough collector. We have modified the existing design of compound parabolic collector using ray tracing method, and redesigned the angular position for better heat collection efficiency. The collected heat will heat up the air present inside the cooking chamber and the sealed airtight mechanism maintains additional pressure inside the chamber to increase the boiling point of fluids present in the foods to be cooked. We have coated an aluminium sheet with carbon nanoparticles prepared from specially processed carbon shoot which ensures excellent heat trapping. The entire model is economic as it is low cost and the adjustable angular placing of the reflectors ensures that it can be used in any latitude or longitude. We have also conducted a comparative study of existing solar cookers and concluded that the new design is 34% more efficient then any other existing solar cooker. Instead of aluminium reflectors, float-glass mirrors have been used to increase the reflection of solar radiation. The cooker is much healthier as it utilises the concept of roasting instead of frying.**

***Index Terms:*—Compound parabolic collector, LASER Tracing, Pressure Dependent Valve, Solar Flickering**

I. INTRODUCTION

Many concentrating technologies have been used for solar heat collection especially cooking. Compound parabolic collectors offer high efficiency but because of their bulky structure they haven't been used much for cooking. Here we have designed a solar cooker for concentrating solar heat on an intermediate metallic collector coated with fine carbon particles which collect the heat and transfer it to the cooking chamber. This way we can control the heat supplied for heating. Being a passive air heated system, the intermediate air eventually overcomes flickering in solar irradiance. It also provides protection from overheating as a safety valve is deployed to let out the heated air in case of overheating. The angle of inclination of the collector has been determined keeping in mind solar irradiance throughout the year.

II. FABRICATION OF CPC:

A. Materials used:

Materials that are used in fabrication of CPC are aluminum frames to hold the mirrors (float glass mirrors). Float glasses are arranged in such a way that 3 mirrors of dimension: 1) [0.32mX 1.2m] , 2) [0.39mX1.2m] & 3) [0.32m X 1.2m] are made a plate like structure that represents one side of the parabolic structure. Similarly, using other mirrors we made another identical plate and place them apart such that the lower mirror has base distance of 0.45m and upper mirrors have top distance of 1.06m.

#	Name of the material	Specification	Quantity
1	Float Glass Mirror	Dimensions: i> 0.32m X 1.2m ii> 0.39m X 1.2m Reflection Efficiency: 38%	4 No.s 2 No.s
2	Aluminum Frames	Dimensions: i> 0.32m X 1.2m ii> 0.39m X 1.2m	4 No.s 2 No.s
3	Gas wielding machine		1

The top mirrors of dimension 0.32mX1.2m are placed at an angle of 77
The middle mirrors of dimension 0.39mX1.2m are placed at an angle of 74˚.

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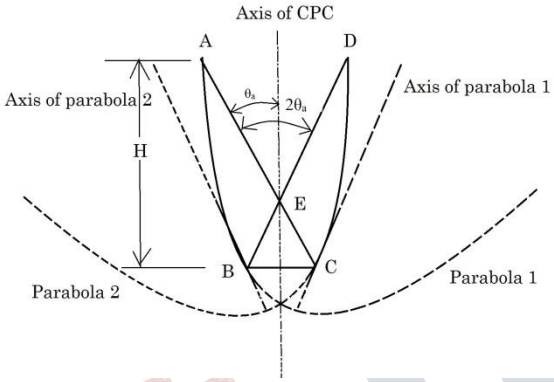
The bottom mirrors of dimension 0.32mX1.2m are placed at an angle of 66˚.

B. Mathematics Used

Two parabola are taken and put in such a way [as given in figure] such that the axis are (24X2)˚ apart i.e. 48˚ apart. The 24˚ is taken s\because the sun varies approximately at ±23.5˚ apart.

So when the sun is even at an angle of 24˚ with the axis of the parabola, the collector retains its efficiency.[1]



C. Reflectors used:

Float glass mirrors are used normally for reflection of sunlight from infinity angle.Here a simple plane mirror is used that contains highly reflective thin aluminum sheets under a transparent glass substrate. The width of the mirror pieces used is nearly 3 mm and are kept least to maintain the total weight of the structure. The glass substrate used above the aluminum sheet should be very thin so that heat doesn't trap..

III. FABRICATION OF COOKING CHAMBER

A.Dimension:

The dimension of the cooking chamber is given by (0.45mX1.2mX0.18m)=0.097m3. i.e. approximately 9 liters. This is the volume of air that is trapped in the cooking chamber under normal temperature and pressure.

B. Construction

The shape of the cooking system is simple cuboidal with one side opening. The cooking chamber is so made that the inside volume remains air sealed, when the opening is closed and the chamber is sealed. A valve is used to release the extra pressure so that it doesn't hamper the structure. The upper portion of the cooking chamber is covered with carbon particles that help in better absorption and uniform distribution inside the chamber.The inner part of cooking chamber is lined with 80 GSM aluminum foil. This is done to decrease the wastage of heat energy from radiating out of the chamber. This thin reflective aluminum coating is used just as a coating and so similar paints can also be applied.

IV. SUPPORTING STRUCTURE:

A. Design

The trough collector that is made is still not ready for any kind of implementation and so it is needed to set in such a position that average sunlight reception is maximum.So the aperture of the trough is set at 23 ˚ and it is made in such a way that the cooking chamber that is attached to the collector is having base parallel to the ground. The stand we used is made of iron bars as the stand is just to hold the trough and has no other mathematical or scientific value. The supporting structure is now suspended to the trough as seen in figure and real pic attached.But the iron bar used for supporting the structure increased the mass of the structure dramatically and so it is very inconvenient to move it. So caster wheels are attached under the supporting structure and for this we came to find that loads are not equidistant and so 8 wheels are attached on the other side.

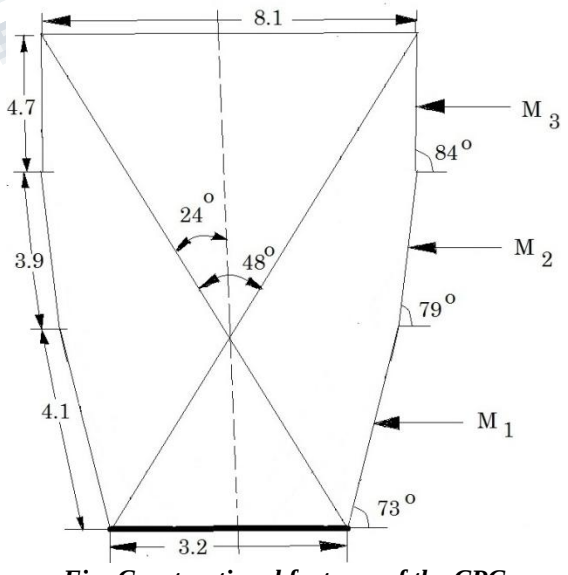


Fig: Constructional features of the CPC

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B.Calculation of angle of inclination:

Both the geographical coordinates and time determines the position of the sun. But due to our trough shape. The position of the sun during a day (i.e. azimuth angle) need not be taken under consideration..[2]

The angle of the sun is given by the angle

The angle of the sun is given by the angle

$$\delta = -23.44^{\circ} \times \cos\left[\frac{360^{\circ}}{365}(X+10)\right]$$ [3]

Where X is the number of days of the year.
At equator
When x=0,
δ= -23.44Xcos(9.863)=-23.094˚

when X=183

δ=-23.44Xcos(0.9863X193)=23.058˚

at latitude 23.5˚ N, $\delta_{X=0}$=0.406 and $\delta_{X=183}$=46.0558

So sun gets diverted in between 0.406˚N and 46.558˚N.

So the average is what the aperture angle of trough should be i.e. 23.48˚.

V. TESTING AND STUDY

A. Preliminary study using LASER

This tracking is done by using visible light rays from diff positions and different angles on the reflectors and recording the path of light in the arrangement. For this method, a 5 mW Red LASER (Ruby) was chosen with a beam diameter of 1.5mm. This light was positioned at various locations at a constant distance from the reflector. The reflection of the light beam was traced each time and the ray tracing diagram was drawn. Then at the same position the tilting angle was changed from zero to twenty degrees in steps of five degree and the angle ray tracing diagram was drawn. It is found that each time the reflected beam reaches the absorbing surface. The same process was repeated with the cooking chamber.[4]

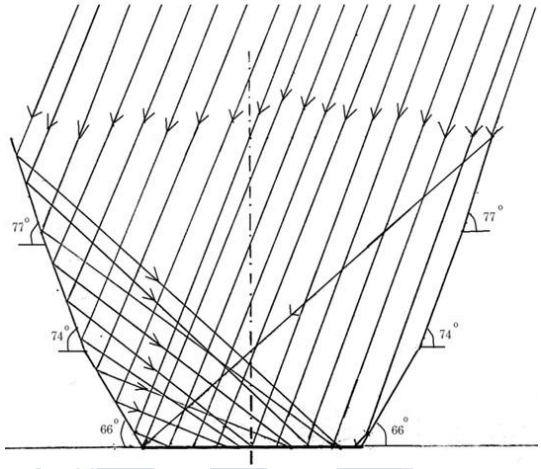
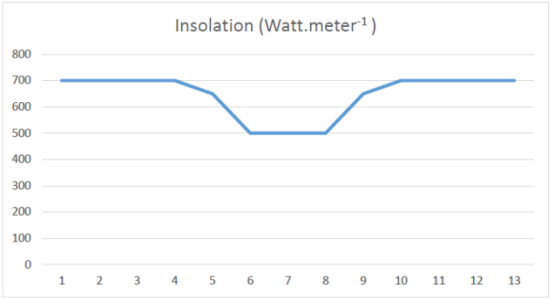


Fig: LASER tracing diagram

VI. PROTECTION AGAINST FLICKERING

One of the biggest disadvantages of solar energy is sudden drop in solar energy intercepted due to cloud cover. The cooker section is made airtight and is insulated by 80 gsmaluminum sheet to minimize the energy loss due to heat dissipation.[5]



Graph: Insolation VS Time graph

VII. SAFETY AND PRECAUTION

Temperature triggered pressure relief valve A pressure relief valve is a safety device designed to protect a pressurized vessel or system during an overpressure event. An overpressure event refers to any condition which would cause pressure in a vessel or system to increase beyond the specified design pressure or maximum allowable working pressure

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(MAWP).[reference] According to Guy-Lussac's Law, as temperature increases the pressure exerted on the walls of a constant volume container increases. Therefore, we can use temperature as a triggering factor. The optimal temperature range of the designed cooker using the CPSC is 100˚-230˚ Celsius. Therefore, the activation temperature of the pressure relief valve is 230˚ Celsius. [6]

A mercury-expansion valve has been used. Mercury expands proportionately with rise in temperature. The length of the piston and the axle has been calibrated to relief the pressure when the mercury expands above the predetermined limit at temperature higher than 230˚ Celsius.

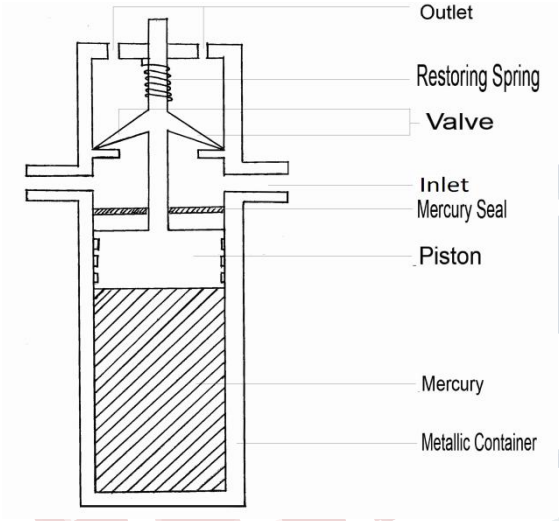

Fig : Mercury based pressure relief Valve

VIII. CONCLUSION

We have made a comprehensive study of the design and fabrication of a solar cooker using a compound parabolic solar collector. Efforts have been taken to increase the efficiency of existing solar cookers by improving the CPSC geometry and also designing a much lossless heat collector. The designed solar cooker has its application in remote rural communities and also in big food chains like KFC, McD to reduce their carbon footprint. Further study can be made to make this solar cooker more consumer friendly.

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