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Performance Evaluation of a Parabolic Dish Solar Thermal Cooker - Review

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ABSTRACT — Cooking is the prime requirement of people all over the world. Solar Energy is contributing major energy requirements of the world population. Parabolic Concentrator is used to utilize the solar energy for heating purposes. The Experimental investigations were carried out to determine performance of solar parabolic cooker during summer season. A parabolic collector having aperture diameter, depth, focal length was selected for fabrication. First the parabolic solar cooker was tested under no load condition, and then cooker filled with different volume of water viz. half, one and two liters along with the suitable quantity of rice. The solar radiation and temperatures of reflector, pot, ambient were recorded. Performance parameters of parabolic concentrator cooker are obtained. The cooking power, standard cooking powers are also calculated. Pressure cooker of 2 liters is used for the experiment. The solar cooker was found to be useful in cooking a variety of foods.

KEYWORDS — Solar Cooker, Heat loss factor, Optical efficiency factor, Cooking power, Solar energy.

I. INTRODUCTION

Solar energy is one of the most promising renewable energy resources which is available in most of the developing countries including India. Cooking in a rural area mainly depends upon conventional energy sources such as cow dung, straw, wood, coal and hence, solar cooking can play an important role in rural areas in cooking. Solar cookers are the most promising devices since firewood used for coking causes deforestation while commercial fuels such as LPG and electricity are not available besides cooking accounts for a major share of energy consumption in developing countries. As the authors know 70% population of India lives in rural areas and there are about 300 sunny days a year in India. Solar thermal is being developed and disseminated in many countries around the world. The Ministry of New and Renewable Energy (MNRE), Govt. of India has been pursuing a comprehensive program in the country on the development and dissemination of renewable energy technologies. Solar cooking saves not only fossil fuels but also keeps the environment free from pollution without hampering the nutritional value of the food. PSC are low cost options for meeting the cooking energy needs as well as environmental protection. [1]

The Parabolic Solar Cooker is an emerging device which has a great potential in India. However, PSC technology will have to compete with prevalent cooking devices in the country. The parabolic solar cooker rests on the principle of the concentration of the rays.

It is well known that the parallel beam of ray of the sun is reflected on the parabolic mirror and the rays converge in the same point, the hearth of the parabola. While running up against a dark container placed in this point, the rays are released their energy in the form of heat. Determination of the exact receiver size and the arrangement to provide insulation at the receiver are of prime importance to avoid thermal losses. One or more transparent covers are employed to reduce the convective and radiative heat losses from the absorber to the environment. Heat losses from a paraboloidal concentrator solar cooker depend on the pot water temperature, the surface area of the cooking pot, the wind speed, and the orientation of the reflectors. The heat losses are classified as Optical losses and thermal losses. Optical losses are those which occur in the path of the incident solar radiation before it is absorbed at the surface of the absorber, while thermal losses are due to convection and reradiation from the absorber. The thermal and optical performance of the paraboloidal concentrator was evaluated by carrying out thermal tests by heating and cooling a known amount of water.

In an attempt to find alternative sources of fuel, solar energy utilization is a big milestone as it is available free everywhere and it costs nothing. The only thing we need to do is to collect it in efficient way and convert in to required form. Solar parabolic cooker is one which collects the light and concentrates at small area so all thermal energy is utilized uniformly over blackened cooker which is specially designed for it. The advantage of using solar cooker are, it emits no harmful gases, nor reason for global warming, it is very environmental friendly. Mainly it is freely available and inexhaustible energy source. When a three dimensional parabola is aimed at the sun, all the light that falls upon its mirrored surface is reflected to a point known as the focus. If a black cooking pot is placed at the focus it will absorb the light's energy and become very hot. A satellite dish is an example of a parabolic that can be made into a cooker. Parabolic Solar cookers heat up quickly and are used like a standard stovetop range to sauté or fry foods, boil water, or even bake bread. They can also be used to generate steam, power sterling engines, crack water to produce H_2 gas and even plasma matter. It is easy to see in today's world that this shape is successful in its use. The parabolic shape can be seen in satellite dishes, radio towers, and yes, even in solar cookers around the world. It is simple to say it works, and just as simple to understand how it works.[1]

II. LITERATURE REVIEW

The first solar parabolic cooker was developed by Ghai. The solar parabolic cooker is a preliminary construction for the experiment. The pot is painted black with dull black paint and water temperature is measured using Copper constant thermocouples. These thermocouples having low cost, acceptable accuracy and rapid response. The coordinates of parabola were obtained by the software called parabola calculator which is easily available on the internet. Cooking with the energy of Sun is not a new or novel idea. According to the Halacy and Halacy design and affordable cost. In an attempt to resolve these issues, a comprehensive study involving theoretical review, development work, experimental testing and evaluation of solar cookers was conducted for several years on different types of solar cookers.

This concept describe the throws light on features, limitations and feasible applications of different solar cookers. This helps the consumer in selecting most effective and appropriate solar cooker. Solar cookers have attracted the attention of many researchers so far. Different types of solar cookers have been developed and tested all over the world. Today, there is challenge to manufacturing and evaluation of efficient and cheap solar cookers. There has been a considerable interest recently in the design, development and testing of various types of solar cookers. (1992) the first Scientist to experiment with solar cooking was a German Physicist named Tschirnhausen (1651-1708). He used a large lens to focus the sun's rays and boiled water in a clay pot. His experiment was published in 1767 by a Swiss Scientist Horace de Saussure who also discovered that wooden "hotboxes", he produced enough heat to cook fruit. French Scientist Ducurla improved on the hot box design by adding mirrors to reflect more Sunlight and insulating box.[2]

Solar cooking is a simple and own technology. Nichols [1993] has shown that the concept of solar cooking began over 220 years ago and was used by the French Foreign Legion starting in the 1870's. It makes possible to reduce the costs of cooking and does not employ any raw material expensive or polluting. Moreover it has a slow cooking; the food is not degraded and preserves all their nutritional and gustatory qualities. All solar cookers work on the principle of concentrating the direct solar rays to raise food or water temperatures to cooking. Cooking temperatures begin at about 65°C although temperatures of 120°C to 200 °C are preferred. Various designs of the solar cookers were studied in order to optimize their performance. They vary by the geometrical form and the place of the cooking pot.

It is well known [Dutta 2003] that an effective solar furnace generally forms part of two categories. One is of type box; the other is with reflectors parabolic focusing. The guiding principle of a standard box solar cooker is to concentrate heat while letting pass the sunlight through a pane in one limps closed well-insulated. The light is 'imprisoned' in the box and is transformed into heat when it is absorbed by the pot. The parabolic solar cooker rests on the principle of the concentration of the rays. It is well known [Mark 2004] that the parallel beam of ray of the sun is reflected on the parabolic mirror and the rays converge in the same point, the hearth of the parabola. While running up against a dark container placed in this point, the rays are released their energy in the form of heat.

Several research works was, conducted in different areas of solar cooking ranging from thermal testing and performance evaluation of different types of solar cooking devices. Such devices include concentrating solar cookers, Parabolic solar cookers, panel solar cookers, hot box solar cookers, square and rectangular box type of solar cookers, Double exposure solar cookers ,solar cookers with thermal storage and many others by various authors with the aim of improving the efficiencies of these cookers. Some of the authors that work in this area include (Ali, 2000)**,** Design and carried out series of test in nine days in other to make comparison of the Sudanese box type solar cooker against the Indian designs. Sudanese solar cooker showed a better thermal performance.

Ibrahim 2005, Conducted an experimental testing of box type solar cooker using the standard procedure of cooking power. The box type solar cooker was tested to accommodate four cooking pots in tatna (Egypt) under prevailing weather conditions. The solar cooker is exposed to solar radiation from the top and bottom sides with a set of plane diffuse refection is used to direct radiation on to lower side of the absorber plate.[3]

Manukaji John conclude that when the aluminum pot was used, the cooker performed satisfactorily and did not deviate much from the initial assumption made during the designing stage. The cooker uses the free renewable energy of the sun. its use zero pollution and reduce "global warming." The food it cooks tastes better and does not destroy the valuable vitamins and nutrients in the food. Solar cookers cannot burn food that is cooked in them.You never have to stir the food as you do on a conventional cookers. Unlike conventional cookers, solar cooking does not heat the kitchen. Since its performance compared favourably with the performance of conventional cookers, its use should be recommended for most African rural and city dwellers.[7]

The collector cannot be easily tilted and oriented, as per the position of the sun with tracking mechanism and external power will be needed. The maintenance cost is minimum and hence economical. Running cost is nil. The labour cost is minimized on account of its simple design. Although the research has its own limitations, that is, intermittent supply of solar energy and converted energy cannot be stored; it is satisfactory considering the market survey report. The use of solar troughs is limited only to clear sunny days. The Solar trough tilting angle is limited to a maximum of 120°. The steam can produce scaling inside the metal absorber pipe and hence, non-corrosive coating should be applied in it. The Tracking Mechanism is of single Axis (North South horizontal). Additional maintenance is required to clean the dirt absorbed on the glass surface. Periodic maintenance is necessary to avoid any complications. Finally, it was concluded that concentration of Solar Energy on Mirror Parabolic Trough Collector has been intensified when compared to Aluminums Parabolic Trough Collector.[8]

III. PROBLEM IDENTIFICATION

This type of cookers usually employs mirrors / reflectors to concentrate the total solar energy incident on the collector surface, so the collector surface is usually very wide and the temperature achieved is very high. Parabolic dish cooker has the highest efficiency in terms of the utilization of the reflector area because in fully steerable dish system there are no losses due to aperture projection effects. Also radiation losses are small because of the small area of the absorber at the focus. Additional advantages include higher cooking temperatures, as virtually any type of food can be cooked, and short heat-up times. In the present work a parabolic dish solar thermal cooker, PDSTC, was designed and constructed. The parabolic solar cooker rests on the principle of the concentration of the rays. It is well known that the parallel beam of ray of the sun is reflected on the parabolic mirror and the rays converge in the same point, the hearth of the parabola. It is obvious that when the parabola is larger, the cooker will be powerful.

IV. SELECTION OF MATERIALS FOR THE CONSTRUCTION OF THE PDSTC

IV. 1 Material for the Body of the Dish

Steel was selected over aluminium because of its strength, durability, and energy effectiveness in use of material. Energy consumed to produce steel is estimated to be16500 kJ/kg compared to that of aluminium of 141,000 kJ/kg [6] commercially-available dish was adopted so as to reduce errors in the process of manufacture: its smooth contour shape minimizes the sloping error of the reflective, glass material.

IV. 2 Material for the Reflecting Surface

A light glass mirror of high surface quality and good specular reflectance was selected. A glass mirror of 2 mm thickness was selected over 3mm- and 4mm-thick glasses to reduce the overall weight of the PDSTC. Glass mirror was selected over polished aluminium surface because its reflectivity of 95% is better than that of aluminium (85%).

IV. 3 Material for the Absorber

Aluminium was selected over copper and steel because of its lower cost, light weight, and ease of fabrication. Its light weight reduces the overall weight of the solar cooker and also reduces the amount of work to be done by the superjack in turning the dish on its axis.

IV. 4 Material for the Absorber Surface Coating

Black paint was selected for the absorber coating. It was selected over other coatings because of its higher absorptivity at angles other than normal incidence, adherence and durability when exposed to weathering, sunlight and high stagnation temperatures, cost effectiveness, and protection to the absorber material.

IV. 5 Food Material and Heat Transfer Fluid

Rice was selected as a representative food to be cooked because it is a staple food for about two-third population of the world. It is also a non-perishable food item and can be cooked simply without adding any additive. Water was selected as the heat transfer fluid because of its stability at high temperatures, low material maintenance and transport costs, safe to use, and is the most commonly used fluid for domestic heating applications.

IV. 6 Material for the Vertical Support of the Dish

A rectangular, hollow, steel bar was selected for the support of the dish and the superjack. This is because of its strength, rigidity, resistance to deflection by commonly encountered winds, and its ability to withstand transverse and cross-sectional loads of the entire heating portion of the PDSTC.

IV. 7 Material for the Base of the PDSTC

A combination of angle and channel-section steel bars were selected for the base which support the whole solar cooker structure. Channel-section and angle bars were chosen to provide solid and rigid support for the rectangular, vertical-axis steel bar which supports the parabolic dish.

IV. 8 Tracking Mechanism

We can use the Electronic control units for tracking the parabolic dish at required direction. In that case we use light detector resistors are used . Using this easily parabolic dish can be move east to west & other direction used one screw arrangement so that mechanism work properly.

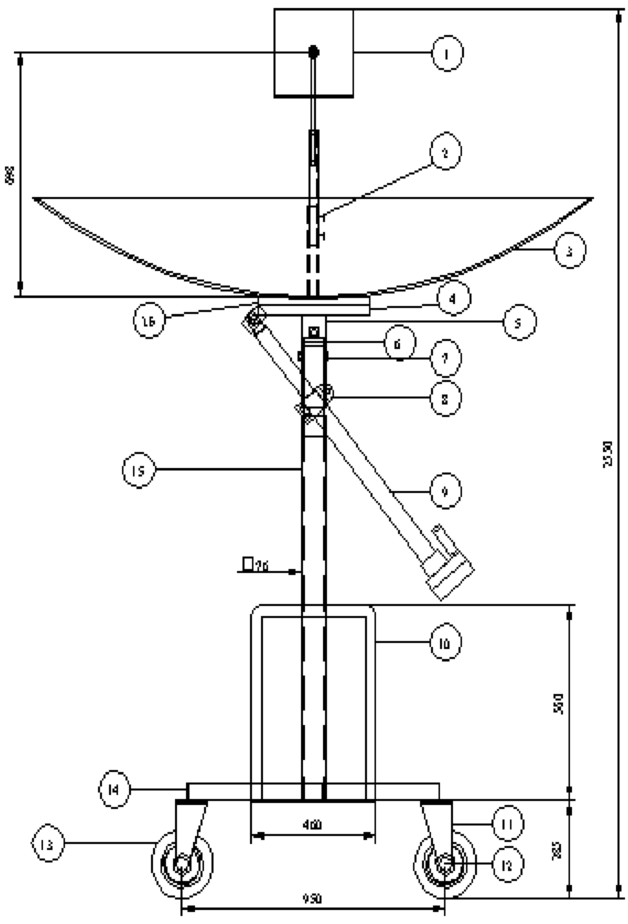
V. EXPERIMENTAL SETUP

The parabolic dish solar thermal cooker consists of following parameters.

S/No.	Item	Material	No. of
1	Absorber	Aluminium	1
2	Screw Lock	Mild Steel	2
3	Paraboli Dish	Mild Steel	1
4	Flat Bar of ATM	Mild Steel	1
5	Aperture Tilting Mechanism ATM	Mild Steel	1
6	Vertical Part of ATM	Mild Steel	1
7	Bolt Lock	Mild Steel	3
8	Clamp	Brass	1
9	Superjack	------	1
10	Handle	Mild Steel	1
11	Wheel Bracket	Steel	4
12	Wheel Axle	Steel	4
13	Wheel	Rubber	4
14	Base Support	Mild Steel	1
15	Trunk	Mild Steel	1
16	Ring Connector	Mild Steel	1

Set up consists of 1. 2 m diameter Concentrator and black coated absorber in the form of cooker as shown in figure 1. The value of the diameter is selected such that heat input available at focal area in the range of 600 watts [2]. The focal area is a white bright spot measured and found to be almost 0.2.m diameter and hence pressure cooker of 0.2m diameter, 0.25m is selected. An anodized aluminium reflector with reflectivity of 82% is fitted over to get the shape of parabola. The parabolic cooker should be placed facing east direction in the morning and the reflector should be tilted according to Sun angles. Lock key is provided to lock the position of reflector. The cooker will reach maximum temperature if tracking is done correctly.

Figure 1 : Actual Working Photograph of PDSTC



VI. PERFORMANCE EVALUATION OF PARABOLIC DISH SOLAR THERMAL COOKER

The performance of paraboloid cooker was evaluated by carrying out the tests suggested by Mullick Traditional methods of characterizing the performance of solar cooker are based on energy analysis based on first law of thermodynamics and it provides information about quantity of energy without investigating quality of energy. Exergy analysis is based on second law of thermodynamics which not only considers the irreversibility in the system but also it is directly related to quality of available energy. Exergy is defined as the maximum work which can be produced by system.[1]

The initial specification for the design of Paraboloid Solar Collector is obtained by considering parabolic equation $X^2 = 4fY$ (1)

Where Y is Distance along vertical axis, f is the Focal length; X is Distance along horizontal axis.

Figure 2: Assembled drawing of the PDSTC
Original scale used 1:15

We used these equations

The focal length of Parabola

$$f = \frac{h^2}{4 \times R} \tag{2}$$

The parabola surface Area

$$As = \frac{8 \times \pi \times f^2}{3}\left[\left(\left(\frac{d}{4 \times f}\right)^2 + 1\right)^{\frac{3}{2}} - 1\right] \tag{3}$$

The Concentration Ratio

$$C_R = \frac{A_{ap}}{A_{ab}} \tag{4}$$

Cooking power

$$P = \frac{Mw \times Cw \times dTw}{dt} \tag{5}$$

Standard cooking power

$$Ps = \frac{700 \times Mw \times Cpw \times \Delta T}{t \times I_b} \tag{6}$$

Thermal Efficiency

$$\eta_t = \eta_0 - U_L \times \frac{A_p \times (T_w - T_a)}{A_a \times I_b} \tag{7}$$

Heat loss factor

$$F'U_L = \frac{(M_{POT} \times C_{POT} + M_W \times C_W)}{A_{POT} \times \tau_0} \tag{8}$$

Optical Efficiency Factor

$$F'\eta_0 = \frac{\frac{F'UL \times A_{pot}}{A_p}\left[\left(\frac{T_{wf} - T_a}{I_b}\right) - \left(\frac{T_{wi} - T_a}{I_b}\right) \times e^{-\frac{\tau}{\tau 0}}\right]}{1 - e^{-\frac{\tau}{\tau 0}}} \tag{9}$$

A] No – Load testing :

To evaluate the thermal performance of the solar cooker, a no-load test was conducted. The pot without load was kept at the focus. The temperature at various points of the pot was measured by thermocouples attached at different locations on the inner surface of the pot. Four thermocouples each were fixed at the pot bottom center, bottom side, side wall, and cover.

The parabolic was adjusted, and the bright spot was positioned at one edge of the bottom of the pot. The concentrator was lifted in this position until the bright spot moved across the bottom of the pot, almost to the diametrically opposite edge. The record of the temperatures at the various points obtained by a multichannel data logger at 10- minute intervals was carefully analyzed.[1]

B] Water Heating and Cooling Tests :

The water heating and cooling tests were performed to determine the optical efficiency factor and overall heat loss factor respectively. The water heating and cooling tests were performed on a paraboloidal concentrating cooker with aperture area. The concentrator was adjusted initially so that the bright spot was positioned on the bottom of the pot near the edge. When the water temperature reach 95 – 97°C, the concentrator was shaded by a large umbrella. The water temperature, ambient temperature, was recorded during the test. [1]

The work is in Progress then After the solar thermal cooker was constructed as like shown in Fig. 1. The all work completed upto 10/03/2016 & reading will be taken after completion. Above cooking tests carried out & overall performance of the cooker is calculated from above all equation.

VII. FUTURE SCOPE OF SOLAR COOKER

Average cost of solar cookers decreases day by day on the contrary their power output and efficiency considerably increases. In the upcoming future, widespread use of this technology is expected hopefully not only in developing countries but also throughout the world. Renewable energy resources will play an important role in the world‘s future. According to the global renewable energy scenario, proportion of the solar thermal applications will be about 480 million tons oil equivalent by 2040. Nowadays, solar cookers are also available to use in the areas with limited solar radiation depending on the developments in solar power concentrating systems and material technology. In addition, the most challenging point of solar cookers, un-available to use when sun goes away, is overcome with thermal energy storage techniques. Briefly, it is anticipated that solar cooking technology will be demanded by a huge group of people in the near future because of its outstanding features.

NOMENCLATURE

Aap = Area of Aperture (m^2)

Aabs = Area of pot (m^2)

As = Surface area of parabola (m^2)

C = Concentration Ratio

Cpw = Specific heat of water

Cpot = Specific heat of Pot f Focal Length (m)

F‘UL = heat loss Factor

F‘η0 = optical Effciency Factor

h = Depth of Parabola(m)

Ib = Beam Radiation (W/m^2)

Mw = Mass of Water (kg)

Mpot = Mass of Pot (kg)

P = Cooking Power (W)

Ps = Standard cooking Power (W)

Ta = Ambient Temperature (˚C)

Twf = Final water Temperature (˚C)

Twi = Initial water Temperature (˚C)

UL = Overall loss Coefficient (W/m˚k)

τ 0 = Cooling time Constant

η 0 = Optical Effciency

ηt = Thermal Efficiency

η = Energy Efficiency

ψ = Exergy Efficiency

VIII. CONCLUSION

My work is in progress then after completion of all work, The parabolic dish solar thermal cooker presents encouraging results while being compared to other types of solar cooker. Solar cooking technology is a key item in order to deal with deforestation. The main research points of this are food-water volume and mass ratios, cooker component design and development, material and labour economy, and energy cost savings. All the components were made from locally available materials. This promotes local content utilisation of manufactured goods and services. The ambient temperature affects the performance of concentric solar cooker on a minor scale in the morning hours. The ambient temperature is less hence the rate heat transfer from the vessel and its contents to the ambient is more hence there is a slight decrease in the efficiency in the morning hours. In the afternoon due the higher ambient temperature there is a less rate o heat transfer correspondingly higher efficiency.

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