IJFEAT
INTERNATIONAL JOURNAL FOR ENGINEERING APPLICATIONS AND TECHNOLOGY

IMPROVEMENT OF THERMAL PERFORMANCE OF BOX TYPE SOLAR COOKER

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***Abstract*-With growth of population and increasing demand of fuel, renewable energy sources give relief to some extent. Utilizing solar energy for the residential and commercial purpose is not only cost effective but also environment protective. This paper reviews idea of utilizing solar energy for cooking of food by employing heat transfer enhancement techniques. With latent heat storage technique using phase change material (PCM), cooking food can be done during late evening too. Identification of appropriate phase change material is a real task. This paper uses various techniques that can be used to increase the thermal performance of box type solar cooker. In the present work Emphasis is given on the method of using lugs, solar cooker with PCM and effective tracking of solar cooker.**

Sufficient care was taken for selecting the materials to be used in this solar cooker with price and availability constraints across rural India. All assumptions for the design are based on this basic aim.

Keywords: Lugs method, Phase change material, Tracking of solar cooker.

I. INTRODUCTION

Solar is important in the current global discussions on energy and environment. World has become more environmental conscious, since there is a rising deforestation and finding renewable energy options to fossil fuels. Currently, solar energy is meeting the energy requirements for a large percentage of the world's population particularly in developing countries. One of the major essential energy needs for human living is for cooking food. The major portion of energy consumption within developing countries is for cooking in the household. In an Indian village, 95% of the energy consumption is for cooking only. Therefore, solar energy harnessing for cooking can prove to be a huge advantage for sustainable development. There has been a considerable recent interest in the improvement of design, development and testing of various types of solar cookers such as box type, concentrator type and oven type around the world. Among various available options of solar cookers, only the box type solar cookers have been used in India majorly because the box type solar cooker is having low cost and also easy to handle and effectively working.

Box-type solar cookers are essentially used for the boiling type of cooking. The temperature of cooking in this case is close to 100°C. A huge fraction of the mass of most food products is because of higher mass percentage of water, and more water may be added in the boiling type of cooking. Therefore, sensible heating up to the cooking temperature requires almost 4.2 kJ/kg °C heat.

Historic review of solar cooking [1]

The development of solar cookers started early from 18th century. Experiments on solar cookers were conducted by a German Physicist named Tschirnhausen (1651–1708). In 1767, French–Swiss Physicist Horace de Saussure tried to cook food via solar energy. In 1830 an astronomer Sir John Herschel made an attempt to cook food in an insulated box cooker. In 1876, W. Adams proposed an octagonal oven equipped with 8 mirrors and one year later Mouchot designed solar cooker. He also wrote the first book on solar energy and its industrial application.

In 1930, India began to investigate solar energy as a viable option for avoiding nature degradation. The first commercial box-type solar cooker was introduced by an Indian pioneer named Sri M.K. Gosh in 1945. In 1950s, Indian researchers planned and constructed commercial solar ovens and solar reflectors, but it proved to be non-viable option because of higher costs. In 1970s as a result of fuel crisis, an intensive interest on renewable energy technologies was reinvigorated worldwide especially in China and India. In 1980s, especially the Governments of India and China improvised and expanded national promotion of box-type solar cookers. In 1987, Mullick et al. devised a method to analyze the thermal performance of solar cookers. In 2000, Funk proposed an international standard for testing solar cookers. It was observed that the resulting solar cooker power curve is a useful device for calculating the capacity and heat storage ability of a solar cooker.

II. LITERATURE REVIEW

Someshwer Dutt Sharma(2004)[3], emphasized that latent heat storage in a Phase Change Material (PCM) is very attractive because it has high storage density with small temperature fluctuations. They demonstrated that, for the development of a latent heat storage system, the choice of the PCM plays an important role in addition to heat transfer mechanism in the PCM. Authors studied about 250 PCMs and more than 220 references [1].

N. M. Nahar (2001),studied the design development and testing of double reflector hot box solar cooker using Transparent Insulation Material (TIM). That was compared with a single reflector box solar cooker without Transparent Insulation Material during the winter season at Jodhpur, Rajasthan. A 40mm thick honeycomb made by using polycarbonate capillaries was encapsulated between two glazing sheets of the cooker to mitigate convective losses from the cover glass. By this method, energy saving is estimated to be 1495.0 MJ of fuel equivalent per year. The shorter payback period infers that the use of the cooker is economical [1]

III. CALCULATIONS OF SOLAR RADIATION

Solar radiation varies with relative motion between earth and sun, in order to calculate the amount of sunlight reaching the ground, elliptical orbit of the Earth and the attenuation by the Earth's atmosphere must be considered. For which the exact location of sun with respect to earth is needed, which can be calculated by below method.

Declination Angle,

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+n)\right]$$

Where, n=Day number of year

Hour Angle,

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta)$$

Day Length,

$$S_{max} = \frac{2}{15}\cos^{-1}(-\tan\phi * \tan\delta)$$

Monthly average of a daily extra terrestrial radiation falling on horizontal surface,

$$H_o = \frac{24}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)$$
$$(\omega_s \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega_s)$$

Monthly average daily global radiations on horizontal surface,

$$\frac{\overline{H_g}}{\overline{H_o}} = a + b\left(\frac{\overline{S}}{\overline{S_{max}}}\right)$$

Monthly average daily diffused radiation on horizontal surface,

$$\frac{\overline{H_d}}{\overline{H_g}} = 1.411 - 1.696\left(\frac{\overline{H_g}}{H_o}\right)$$

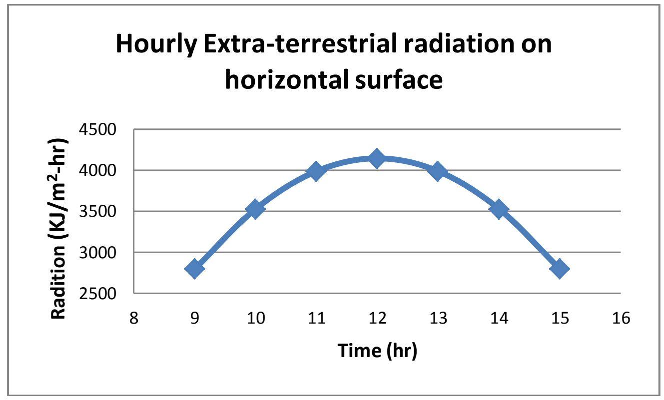

Fig .1 Hourly Extra-terrestrial radiations on horizontal surface

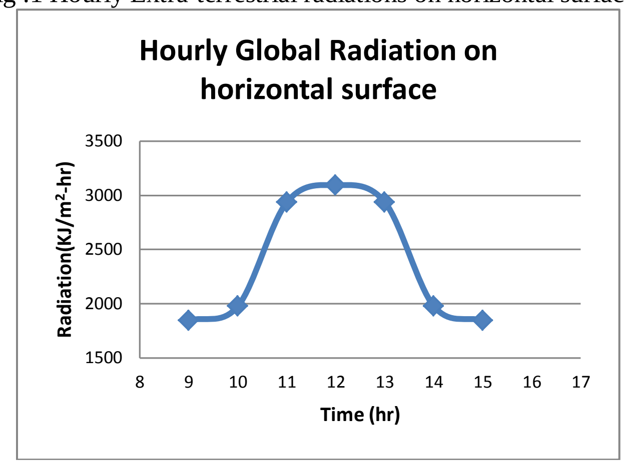

Fig. 2 Hourly Global Radiation on horizontal surface

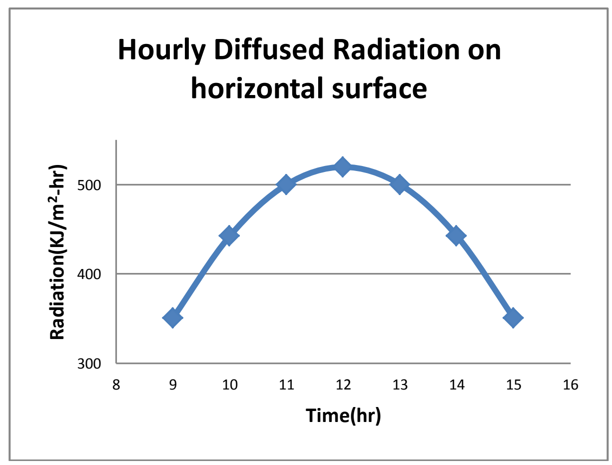

Fig.3 Hourly Diffused Radiation on horizontal surface

Above method was used to calculate beam radiation and diffused radiation on the earth's surface. Fig 1, Fig 2 and Fig 3 are graphs are plotted for lonavala (18.7481o N, 73.4072o E) on Feb. 6 2016 depicting hourly radiations.

IV. METHODS FOR ENHANCEMENT OF PERFORMANCE

To improve thermal performance and heat transfer rate following methods are used:

A) Lugs Method.
B) PCM (Phase Change Material).
C) Solar tracking system.

A. Lugs Method

The heat transfer coefficient inside a box can be increased by increasing surface area. This can be done by introducing Lugs under cooking vessels. The Lugs is nothing but a stand to carry a vessel, due to this the surface area beneath the vessels are available to the rays of the sun. Due to this the surface heating area increases and more heating zone is available.

Heat transfer rate is given by,

$Q=h*A*\Delta T$

Where, Q is Rate of heat transfer

h= coefficient of heat transfer,

A=available area, and ΔT is change in temperature

Since, Q α Area

$$\frac{Q1}{Q2} = \frac{A1}{A2}$$

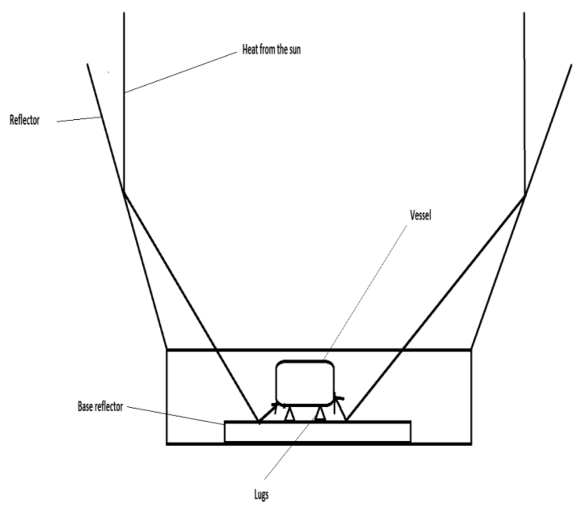

Fig.4 Lugs method

B. Phase change material:

PCM's are latent heat storage materials. The chemical bonds within the PCM break up, as the source temperature rises. The phase change is endothermic process and therefore PCM absorbs heat. The effect of latent heat storage has two main advantages [3]

1. One can store large amounts of heat with small temperature changes and therefore to have a high storage density can be obtained.

2. Since phase change process takes place constant temperature and it takes some time to complete, it is possible to achieve smooth temperature variations. They store 5 to 15 times more heat per unit volume than sensible storage materials such as water, masonry, or rock.

Thermo physical properties of PCM:
1) PCM has high latent heat of fusion per unit volume.
2) PCM has high specific heat.
3) PCM has high thermal conductivity.

Kinetic properties:
1) High nucleation rate.
2) High rate crystal growth.

Chemical properties:
1) Complete reversible melt cycle.
2) Chemical stability is more.
3) Non corrosiveness to the construction materials.
4) Non-toxic, non-explosive.

Latent Heat Storage [4]:

Latent Heat Storage (LHS) is based on the concept of heat release or absorption when a storage material undergoes a phase change from solid state to liquid state or liquid to gas. The storage capacity of the latent heat storage system with a PCM medium is given by the expression:

$$Q_L = \int_{Ti}^{Tm} m C_p \, dT + m a_m \Delta h_m + \int_{Tm}^{Tf} m C_p \, dT$$

$$Q_L = m[C_{sp}(T_m - T_i) + a_m \Delta h_m + C_{lp}(T_f - T_m)]$$

In the present work use of "Stearic acid" as a phase change material is proposed. Stearic acid is also called as Octadecanoic acid [CH3(CH2)16COOH]

Physical properties of stearic acid are [5]:

Melting temperature	52o
Density	847-965(kg/m3)
Appearance	white solid
Flash point	358oF (1960C)
Boiling point:	3830C

C. Tracking of solar cooker:

A solar oven's cooking temperature is reached when steady state thermal equilibrium is reached. Thus, at steady state oven's cooking temperature is a balanced between solar gain and heat losses.

Heat losses fall into five categories:
1. Loss due to reflection
2. Loss due to absorption.
3. Transmitted Losses
4. Leakage Losses
5. Food losses (Heat Lost to Cooking)

Solar gain is a factor to evaluate the total area exposed to the sun and the effectiveness of collection. For the reflectors, this property of solar gain is acceptable but for the cover glass, light must enter the cooking chamber else the mirrors are of no use. Analogically, as stone skips across water, sunlight will skip off the surface of glass without penetrating if the angle is too shallow.

From fig. 5 it can be seen that, an angle of about 30 degrees from the vertical for the mirrors or reflectors yields good penetration with a healthy spread for an optimum use of materials. It can be seen that a reflector equal to the width of the cooking chamber produces an optimum design for use of materials. With such a favorable set of conditions the reflectors can be folded to cover the cooking chamber making the cooker portable for use. Mirrors have a reflection of about 99% but lose around 6% each time the light passes through the glass. Polished metal surfaces have about 90% reflection but no losses due to refraction through glass. The result is that each behaves about the same. Light incident on the extreme edge of the reflector should enter the cooking chamber at the extreme edge opposite the reflector to be beneficial.

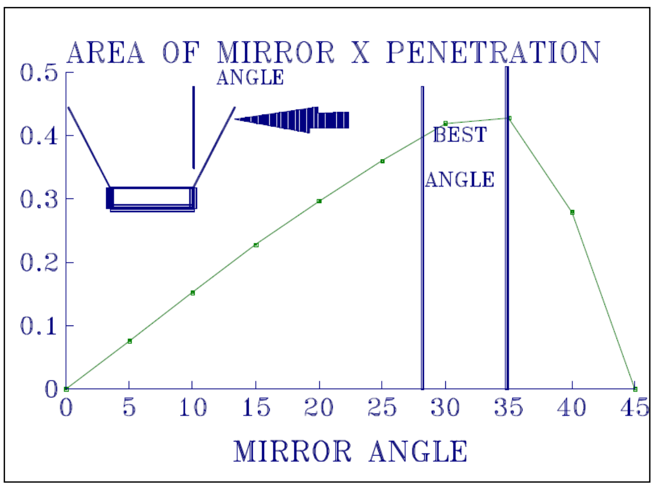

Fig.5 Area of penetration

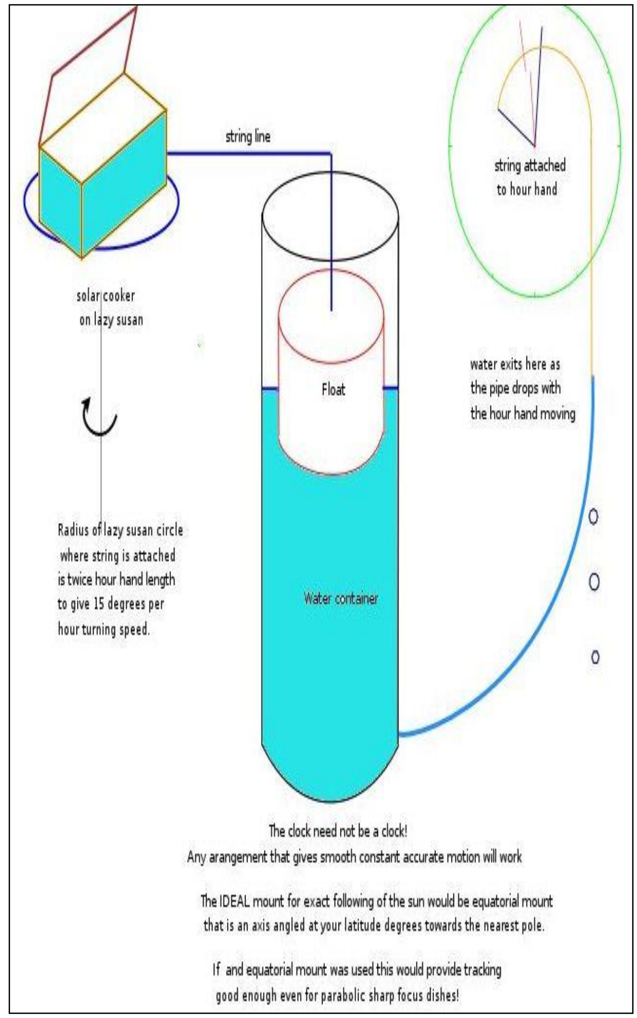

Fig 6 Tracking of solar cooker

An angle of 30 degrees from the vertical (or 60 degrees from the horizontal) with each reflector having the width of the cooking chamber will allow all the light striking the reflectors to enter the cooking chamber. With this geometry mirrors can still be folded. An optimum sized cooker will cook any kind of food that is put inside. Increasing size of the reflectors to make the collector larger will produce more heat gain and will cook food at earliest. If reflectors are extended the cooker becomes less portable. Making the length of the reflectors twice it original size, increases its width by around 20%, because the angle must be steeper. The shallow sun angle on the reflectors makes them increasingly reflective. The penetration into the cover glass improves to some extent because of the more vertical angle. From total of five factors affecting a cooker's cooking temperature three of them was result of thermal losses. Transmitted losses can be controlled with insulation. Double glass covers have twice as much insulation value as that of single glass covers. Leakage losses can be controlled with good tight construction. The chamber should be well pressure sealed and protected from moisture on the inside.

Solar heat is transferred to the food by three mechanisms. First by direct solar rays, that is sunlight incident on the food directly. This is similar like a boiler. Second by convection, heat is transferred from hot air surrounding the food to food inside the chamber. Third, heat is conducted through the tray on which chamber rests. If the tray is made of a heavy metal conductor such as steel or aluminum the sun's rays will heat the tray and heat will be conducted under the food like a stove. All three mechanisms combine to make the food cooking process efficient. Finally, as the sun's energy is transferred into the food the thermal loss decreases the oven's temperature 25 to 50 degrees initially. This loss is only temporary. As the food approaches the oven's temperature the aroma begins to fill the air, that's the whole idea behind solar cooking.[6]

V. CONCLUSION

Present work reviews methods to increase the thermal performance of solar cooker. Traditional fuels like wood pellets, kerosene, and dung cakes utilization must be reduced to minimum level with the help of developed solar cookers. Such an effort will not only be useful in improving the quality of life but also in aid in environmental protection. An efficient and economical model can be made by incorporating methods discussed in the paper. The estimated efficiency rise over conventional solar cooker is 10-20%. Apart from this, in the field of solar cooking the available thermal energy storage technology for solar cookers, with the storage unit, food can be cooked at late evening, while late evening cooking was not possible with a conventional design of solar cooker. Solar cooker with storage unit proves beneficial for the cooking methodologies and as well as for the energy conservation. Many of PCM's are being researched for solar cooking but stearic acid (commercial grade) is commonly used due to easy availability and economically suitable till now.

Nomenclature:

δ = Declination Angle

ω_s = Hour Angle

ϕ = Latitude in degree

n= Number of days

$\overline{S}$ = Average sunshine a day

$\overline{S}_{max}$ =Day Length

$\overline{H}_o$ = Monthly average of a daily extra- terrestrial radiation falling on horizontal surface.

$\overline{H}_g$ = Monthly average daily global radiations on horizontal surface

$\overline{H}_d$ = Monthly average daily diffused radiation on horizontal surface.

am = Fraction melted

ar = Fraction reacted

ck = Specific heat of phase k in PCM (J/kg 8C)

C_{ap} =average specific heat between Ti and Tf (J/kg K)

C_{lp} =average specific heat between Tm and Tf (J/kg K)

C_p =specific heat (J/kg K)

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