An Overview of Solar Cooking, with the help of Phase Changing Material and Solar Tracker

Shweta Singh [1] Abhishek Saroj[2] Dr. Narendra Singh[3]
[1]M.Tech. Student [2]Guest Lecturer [3]Assistant Professor
[1,2,3]Department of Mechanical Engineering
[1,2,3]MMMUT, Gorakhpur, U.P.

Abstract— This paper presents a short review on the different type of solar cookers, phase changing materials and tracking mechanism used in solar cookers. In present scenario renewable sources of energy are widely used for different purposes because these sources provide clean and renewable energy. Demand of clean and renewable energy is increasing day by day. Solar energy is inexhaustible source of renewable energy so various features are used for enhancing its capacity and effectiveness. Solar tracker and phase changing materials are used for increasing the efficiency of the solar cooker.

Key words: Solar Cooking, Phase Changing Material, Solar Tracker

I. INTRODUCTION

The first Scientist to experiment with solar cooking was a German Physicist named Tschinhausen (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.

The Solar cookers are needed due to –

- High cost or Unavailability of commercial fuels – Kerosene, Coal, cooking gas and Electricity.
- Deforestation caused by increasing firewood consumption.
- Use of dung and agricultural waste as fuels, instead of for soil enrichment.
- Diversion of human resources for fuel collection.

II. WORKING OF SOLAR COOKER

Cooking with the energy of Sun is not a new or novel idea. Different types of solar cookers have been developed and tested all over the world. Today, there is big challenge to manufacture an efficient and cheap solar cooker.

All solar cookers work on the principle of concentrating the direct solar rays to raise food or water to cooking temperatures. Cooking temperatures begin at about 150 degrees F. although temperatures of 250 to 400 degrees F. are preferred. Open reflector type solar cookers focus the sun's rays on open cooking pots or pans. Solar ovens trap the sun's heat inside insulated boxes with transparent lids.

A solar oven's cooking temperature is reached when the solar gain equals the heat losses. Thus an oven's cooking temperature is a balance between solar gain and heat losses. Heat losses fall into five categories:

- Reflective losses
- Absorption Losses
- Transmitted Losses
- Leakage Losses
- Food losses

(Heat Lost to Cooking)

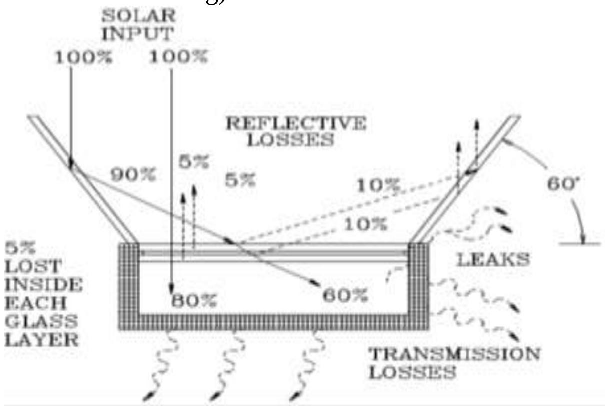

Fig. 1 Losses in solar cocker

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

An angle of about 30 degrees from the vertical for the mirrors or reflectors yield good penetration with a healthy spread for an optimum use of materials. As it turns out a reflector equal to the width of the cooking chamber produces an optimum design for use of materials.

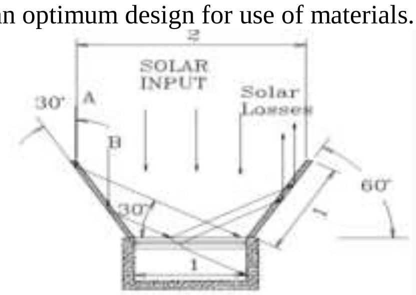

Fig. 2: Optimum angle of reflector in solar cocker

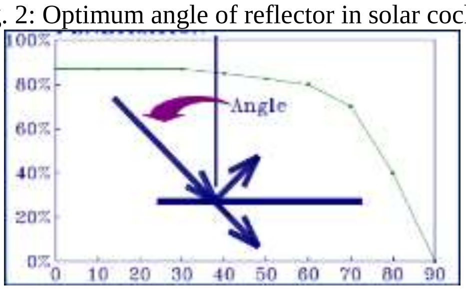

Fig. 3 Graph between percentage loss and angle of reflector

With such a fortunate set of circumstance the reflectors can be folded to cover the cooking chamber making the cooker portable. Mirrors have a reflection of about 99% but lose 5% each time the light passes through the glass. Polished metal surfaces have about 90% reflection but no losses due to glass. The result is that each behaves about the same.

Light striking the far edge of the reflector should enter the cooking chamber at the far edge opposite the reflector to be beneficial. The penetration into the cover glass improves somewhat because of the more vertical angle. Of the five factors affecting a cooker's cooking temperature three of them were thermal losses. Transmitted losses are controlled with insulation. Double glass covers have twice as much insulation value as single glass covers. Leakage losses are controlled with good tight construction. The chamber should be well fitted and protected from moisture on the inside. Solar heat is transferred into the food by three mechanisms. First by direct solar rays, that is sunlight striking the food directly. This is somewhat like a broiler. Second by convection, that is by the hot air surrounding the food inside the chamber. Third by conduction of heat from the tray upon which the food 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 food like a stove. All three mechanisms combine to make the food cooking process very efficient.

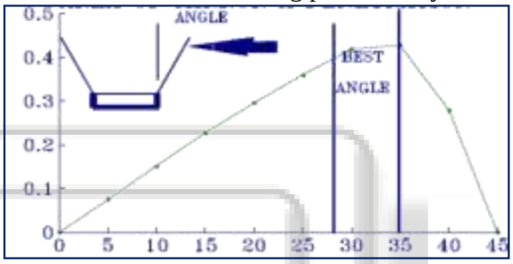

Fig. 4 Graph showing the range of best angle for minimum losses

Finally, as the sun's energy is transferred into the food the thermal loss drops 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.

III. TYPES OF SOLAR COOKER

A. Box cooker

A box cooker is a well-insulated box within a box with a glazed top and a hinged lid that reflects the rays of the sun into the box. When the lid is propped open and the box is turned to face the sun, food in dark, covered pots in the oven reaches the cooking temperature.

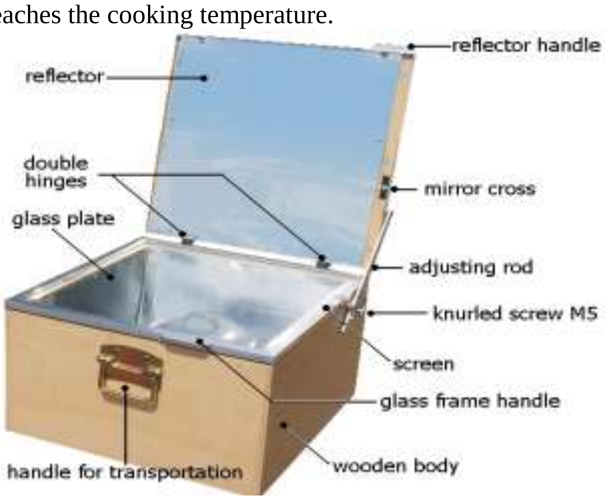

Fig. 5 Different parts of box type solar cocker

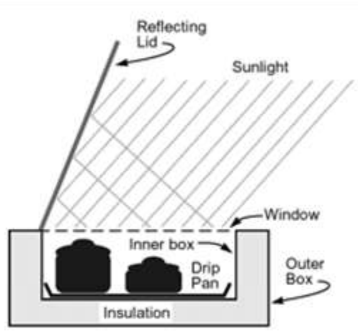

Fig. 6 working of box type solar cocker

B. Panel Cooker

A panel cooker is a reflective panel that directs sunshine onto a dark- colored cooking pot enclosed in a clear insulating shell such as a plastic


Fig. 7: Outline of solar panel cocker

High- temperature cooking bag or an inverted bowl. The shell lets in sunlight and traps the heat. Food in the dark-colored pot typically cooks at temperatures between 200^{o} F and 275^{o}F.

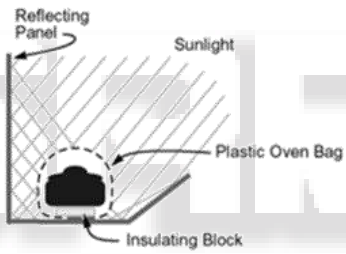

Fig. 8: working of solar panel cocker

C. High Temperature Cookers

High-temperature reflector cookers typically use a parabolic mirror to focus sunlight on a cooking vessel. The focal point of the parabola can become very hot indeed- typically reaching temperatures of 600^{o}F and above – in a very short time, making cooking with one of these similar to cooking on a conventional stovetop. Besides a parabola, other mirror geometries can be used to create the focal point segmented near parabolas, Fresnel mirrors and the three circle geometry popular in china. All the use same principle.

IV. SOLAR COOKER WITH TRACKER

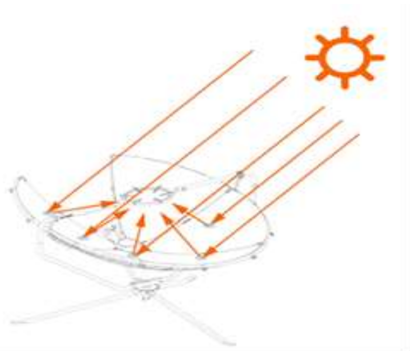
Fig. 9 solar cockers with tracker

Solar Tracker is a Device which follows the movement of the sun as it rotates from the east to the west every day. The main function of all tracking systems is to provide one or two degrees of freedom in movement. Trackers are used to keep solar collectors/solar panels oriented directly towards the sun as it moves through the sky every day. Using solar trackers increases the amount of solar energy which is received by the solar energy collector and improves the energy output of the heat/electricity which is generated. Solar trackers can increase the output of solar panels by 20-30% which improves the economics of the solar panel project.

A. Need for Solar Tracker

The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel. The table shows the Direct power lost (%) due to misalignment (angle i).

Misalignment (angle *i*)	Direct power lost (%)=1-cos(i)
0^{0}	0
1^{0}	.015
3^{0}	.14
8^{0}	1
23.4^{0}	8.3
30^{0}	13.4
45^{0}	30
75^{0}	>75

Fig. 10: Relationship between misalignment angle and direct power lost

The sun travels through 360 degrees east-west a day, but from the perspective of any fixed location the visible portion is 180 degrees during a 1/2 day period. Local horizon effects reduce this somewhat, making the effective motion about 150 degrees. A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees on either side, and thus, according to the table above, will lose 75% of the energy in the morning and evening. Rotating the panels to the east and west can help recapture these losses. A tracker rotating in the east-west direction is known as a single-axis tracker.

The sun also moves through 46 degrees north-south over the period of a year. The same set of panels set at the midpoint between the two local extremes will thus see the sun move 23 degrees on either side, causing losses of 8.3% A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker.

B. Types of solar trackers

There are mainly two types of solar tracking systems which are described as **–**

C. Passive tracking systems -

The passive tracking system realizes the movement of the system by utilizing a low boiling point liquid. This liquid is vaporized by the added heat of the sun and the center of mass is shifted leading to that the system finds the new equilibrium position.

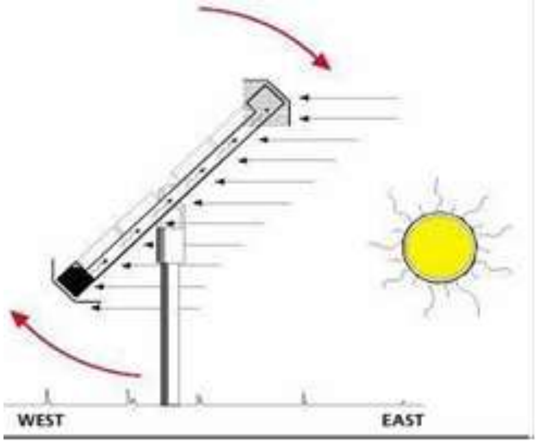

Fig. 11 Passive tracking system

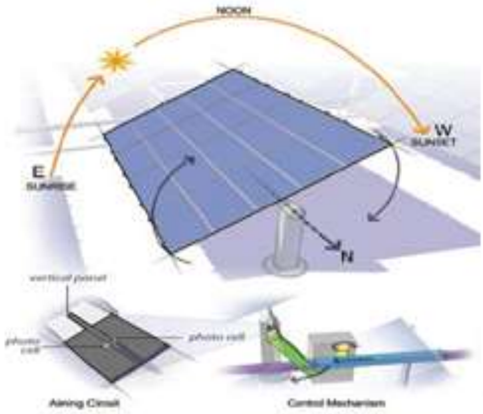

Fig. 12 Different parts of passive tracking system

D. Active tracking systems -

The two basic types of active solar tracker are single-axis and double-axis.

1) Single axis trackers

The single axis tracking systems realizes the movement of either elevation or azimuth for a solar power system. Which one of these movements is desired, depends on the technology used on the tracker as well as the space that it is mounted on. For example the parabolic through systems utilize the azimuthally tracking whereas the many rooftop PV-systems utilize elevation tracking because of the lack of space.

Single axis trackers have one degree of freedom that acts as an axis of rotation. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT) and vertical single axis trackers (VSAT).

2) Dual Axis Trackers

Dual axis trackers as shown in the figure, have two degrees of freedom that act as axes of rotation. Double-axis solar trackers, as the same suggest, can rotate simultaneously in horizontal and vertical directions, and s o are able to point exactly at the sun at all times in any location.

Dual axis tracking systems realize movement both along the elevation- and azimuthally axes. These tracking systems naturally provide the best performance, given that the components have high enough accuracy as well.

Fig. 13 Active tracking system

V. PHASE CHANGING MATERIAL

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amount of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units.

The use of a solar cooker is limited because cooking of food is not possible due to frequent clouds in the day or in the evening. If storage of solar energy can be provided in a solar cooker, then there is a possibility of cooking food during clouds or in the evening and the storage will increase the utility and reliability of the solar cookers. Hence, PCM is the best option to store the solar energy during sun shine hours and is utilized for cooking in late evening/night time Phase Change Materials (PCM) are latent heat storage materials. As the source temperature rises, the chemical bonds within the PCM break up as the material changes phase from solid to liquid (as is the case for solid-liquid PCMs, which are of particular interest here). The phase change is a heat-seeking (endothermic) process and therefore, the PCM absorbs heat. Upon storing heat in the storage material, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process is finished. The heat stored during the phase change process (melting process) of the material is called latent heat. Latent heat storage has two main advantages: (i) it is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density; (ii) because the change of phase at a constant temperature takes some time to complete, it becomes possible to smooth temperature variations. The comparison between latent and sensible heat storage shows that using latent heat storage, storage densities typically 5 to 10 times higher can be reached.

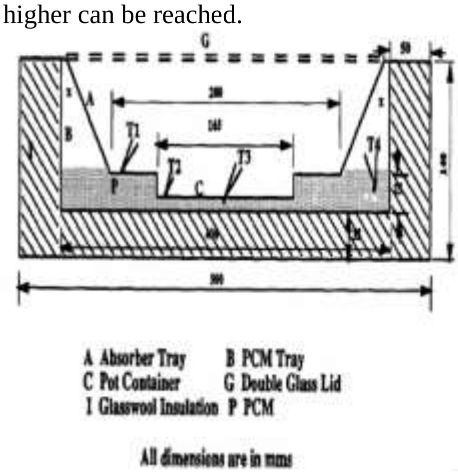

Fig. 14 Solar cocker with phase changing material

A. *Different types of Phase Changing Material -*

Some very common phase changing material which are used widely in the solar cooking are shown in the table given below-

Sr. No.	Phase Changing Material	Mode of Cooking	Maximum Temperature
1.	Salt Hydrate	Flate Plate solar cooker	120°C
2.	Magnesium Nitrate Hexa-Hydrate	Solar box Cooker with multi step inner reflector	95°C
3.	Coconut oil	Flate plate solar cooker	150°C
4.	Stearic acid	Solar box Cooker	122°C
5.	Polyethylene	Solar box Cooker	132°C
6.	Acetamide	Solar box Cooker	127°C
7.	Engine oil	Solar box Cooker	105°C
8.	Acetanilide	Solar box Cooker	135°C
9.	Magnesium Nitrate	Flate Plate solar cooker	140°C
10.	Acetamide PCM-A-164	Concentrating cooker	140°C
11.	Acetanilide MgCL	Integrated Solar Box Cooker	134°C
12.	Erythritol	Solar Cooker integrated with ETC	138°C

Table 1 Different type of phase changing material

VI. CONCLUSION

Cooking energy plays an important role in sustainable energy management in Indian households as well as worldwide. There are various options to meet the end user needs using both commercial and non-commercial energies. Traditional fuels like wood pellets, dung cakes, and kerosene utilization must be minimized with the developed solar cookers. This will lead to a reduction in human drudgery. Such an effort will not only be useful in improving the quality of life but also in environmental protection. This paper focuses on several qualities of solar energy such as; a free fuel from the sky, environment friendly, huge availability of almost places, low or no running cost, good saving, minimization of the monthly electricity bill, accident free, less attention is required etc. Apart 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 simple solar cooker. So that, solar cooker with storage unit is very beneficial for the cooking methodologies and as well as for the energy conservation. Many of PCM's are under testing for solar cooking but stearic acid (commercial grade) is commonly used due to easy availability and economically suitable till now.

REFERENCES

[1] J.R. Williams, Solar energy, technology and applications, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1975.
[2] C.C. Furnas, The use of solar energy, 68-74, 1989.

[3] S.D. Sharma, H. Kitano and K. Sagara, "Phase change materials for low temperature solar thermal applications", Res. Rep. Fac. Eng. Mie Univ., Vol. 29, pp. 31-64, 2004.
[4] J.A. Duffie and W.A. Beckman, Solar engineering of thermal process, 3rd ed, John Wiley Publications, 2006.
[5] J. Wei, Y. Kawaguchi, S.Hirano, H. Takeuchi, "Study on a PCM heat storage system for rapid heat supply", Applied Thermal Engineering, Vol. 25, pp. 2903-2920, 2005.
[6] M. Wentzel and A. Pouris, "The development impact of solar cookers: A review of solar cooking impact research in South Africa", Energy Policy, Vol. 35, pp. 1909-1919, 2007.
[7] M. Kenisarin and K Mahkamov, "Solar energy storage using phase change materials", Renewable and Sustainable Energy Reviews, Vol. 11, pp. 1913-1965, 2007.
[8] R.J. Goldstein , W.E. Ibele, S.V. Patankar, T.W. Simon, T.H. Kuehn, P.J. Strykowski, "Heat Transfer—A Review of 2003 Literature", International Journal of Heat and Mass Transfer, Vol. 49, pp. 451-534, 2006.
[9] M.F. Demirbas, "Thermal Energy Storage and Phase Change Materials: An overview", Energy Sources, Part B, Vol. 1. pp. 85-95, 2006.
[10] M.R.I. Rmadan, S. Aboul-Enein and A.A. EL-Sebaii, "A model of an improved low cost indoor solar cooker in Tanta", Solar & Wind Technology, Vol. 5, pp. 387-393, 1988.
[11] R. Domanski, A.A. EL Sebaii, M. Jaworski, "Cooking during off sunshine hours using PCMs as storage media", Energy, Vol. 20, pp. 607-616, 1995.
[12] I. Haraksingh, L.A. Mc'Doom and O.ST. C. Headley,"A natural convection flat plate collector solar cooker with short-term storage", WREC 1996.
[13] D. Buddhi and L.K.Sahhoo, "Solar cooker with latent heat storage: design and experimental testing", Energy Conversion Management, Vol. 38, pp. 493-498, 1997.
[14] S.S. Nandwani, J. Steinhart, H.M. Henning, M. Rommel and V. Wittwer, "Experimental study of multipurpose solar hot box at Freiberg, Germany", Renewable Energy, Vol. 12, pp. 1-20, 1997.
[15] S.D. Sharma, D Buddhi, R.L Sawhney, Atul Sharma, "Design, development and performance evaluation of a latent heat storage unit for evening cooking in a solar cooker", Energy Conversion and Management, Vol. 41, pp. 1497-1508, 2000.
[16] G. Oturani, N. Ozbalta and A.Gungor, "Performance analysis of a solar cooker in Turkey", Int. J. Energy Res., Vol. 26, pp.105- 111, 2002.
[17] D. Buddhi, S.D. Sharma and Atul Sharma, "Thermal performance evaluation of latent heat storage for late evening with three reflectors", Energy Conversion and Management, Vol. 44, pp. 809-817, 2003. MIT International Journal of Mechanical Engineering, Vol. 3, No. 2, August 2013, pp. 91–95 ISSN No. 2230–7680 © MIT Publications
[18] S.D. Sharma, T. Iwata, H. Kitano, K. Sagara, "Thermal performance of a solar cooker based on an evacuated tube solar collector with a PCM storage unit", Solar Energy, Vol. 78, pp. 416-426, 2005.
[19] H.M.S. Hussein, H.H. El-Ghetany, and S.A. Nada,"Experimental investigation of novel indirect solar cooker with indoor PCM thermal storage and cooking unit", Energy Conversion and Management, Vol. 49, pp. 2237-2246, 2008.
[20] C.R. Chen, A. Sharma, S.K. Tyagi and D. Buddhi, "Numerical heat transfer studies of PCMs used in a box-type solar cooker", Renewable Energy, Vol. 33, pp. 1121-1129, 2008.
[21] R.M. Muthusivagami, R. Velraj and R. Sethumadhavan, "Solar cookers with and without thermal storage—A Review", Renewable and Sustainable Energy Reviews, Vol. 14, pp. 691- 701, 2009.
[22] A.A. EI-Sebaii, S. AL-Amir, F. M. AL-Marzouki, A.S. Faidah, "Fast thermal cycling of acetanilide and magnesium chloride hexahydrate for indoor solar cooking", Energy conversion and Management, Vol. 50, pp. 3104-3111, 2009.
[23] A. Saxena, Varun, G. Srivastava, "A technical note on performance testing of a solar box cooker provided with sensible storage material on the surface of absorbing plate", Int. J. Renewable Energy Technology, Vol. 3, pp. 165-173, 2012.
[24] S.C. Mullick, T.C. Kandpal, A.K. Saxena, "Thermal test procedure for box type solar cooker", Solar Energy, Vol. 39,pp. 353-360,1987.

