Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 10; April-June, 2015 pp. 82-87

http://www.krishisanskriti.org/jmsme.html

# Development of Solar Cookers for day and off Sunshine Hours: A Review

**Sunil Kumar[1] and Munish Gupta[2]**

*[1]M.Tech. Research Scholar, Department of Mechanical Engineering, Guru Jambheshwar University of Science & Technology, Hisar (India)-125001*
*[2]Department of Mechanical Engineering, Guru Jambheshwar University of Science & Technology, Hisar (India)-125001*
*E-mail: [1]ersunil057@gmail.com, [2]mcheeka@ reddifmail.com*

**Abstract—***Solar energy which is clean, abundant, safe, is an attractive solution to substitute conventional fuels for cooking. In India, energy requirement for cooking accounts 36% of total primary energy consumption. The rural and urban population, depend mainly on non- commercial fuels such as wood and charcoal to meet their energy demands. Solar cooking is one of the possible solution but its acceptance has been limited partially due to some barriers. Solar cooker cannot cook food in the late evening or during off sunshine. By the storage unit associated within a solar cooker we can improvise the cooking and reduce the cooking time during day and off sunshine hours. Cooking during off sunshine hours can be done with the help of thermal storage unit using PCMs and other heat storage material associated with the solar cooker unit. So In this paper, a thorough review of the available literature on solar cooker providing cooking during day off- sunshine hours is presented.*

**Keywords***: Solar Cooker, Thermal storage unit, PCM, Efficiency, Cooking power*

## 1. INTRODUCTION

Energy affects all aspects of modern life. The demand for energy is increasing at an exponential rate due to the exponential growth of world population. Advanced energy-efficiency technologies reduce the energy needed to provide energy services, thereby reducing environmental and national security costs of using energy and potentially increasing its reliability. Energy resources are not used for their own sake, but for the services they provide. These energy services are fundamental to our modern economy; they heat, cool, and light our buildings; power our industrial processes; process our food; fuel our transport; and energize our communications and information technologies. Energy is a thermodynamic quantity that is often understood as the capacity of a physical system to do work. Besides its physically meaning, energy is vital for our relations with the environment. Fossil fuels are the main sources of energy. Either they are used directly or converted into some usable form like electricity and transported to homes and industries. The use of energy plays a very vital role in development of individual and country. Fossil fuel based energy resources still predominate with the highest share in global energy consumption. Solar energy is most promising choice because of its free availabilty, cleanliness and friendly to environment. Solar energy offers a wide variety of applications in order to harness this available energy resource. Among the various applications of solar energy, solar cooking is considered as a simple, the most viable and attractive options in terms of the utilization of solar energy. The energy required for cooking is supplied by non-commercial fuels like coal, agricultural waste, dung and oil. In India, energy demand for cooking accounts for 36% of total primary energy consumption. People in rural areas have no choices but to walk several kilometers every day to collect firewood. Besides the environmental and economic burden of noncommercial fuels, there are some serious health problems such as burns, eye disorder and lung diseases originate from the utilization of firewood. Therefore there is a rising attention concerning the renewable energy options to meet the cooking requirements of people in developing countries. In this paper, a review has been carried out on the history of various types of existing/ prevailing solar cooking options during the day time and for off- sunshine hours by using PCMS and other heat storage material.

## 2. SOLAR COOKER

Solar energy is everywhere. From dawn until dusk, the sun's rays beat down on Earth, providing warmth and light. The solar energy hitting Earth each year exceeds the total energy consumed by humanity by more than 20,000 times. But once the sun sets, or clouds fill the sky, our supply of solar energy is cut off. Solar cooker is a tool of harnessing solar energy for cooking. First of all solar cooker is used in 17th century but at that time it not used for commercialization. It is used for experimental work only. Solar cookers are used for cooking in the mid of 18th century. In India solar cookers are used for cooking around mid1950s. Lot of research work are done on solar cookers in India and the rest of the world. Different researchers developed different type of solar cookers to improve the cooking efficiency and economy. Solar cookers have vast variety and it is difficult to classify them. The main important types of solar cookers which are widely used are shown in figure 1. Direct type solar cooker and indirect type solar cooker are the main types of cooker with and without thermal storage unit. During off sunshine hours and cloudy periods thermal storage unit provides energy for cooking.

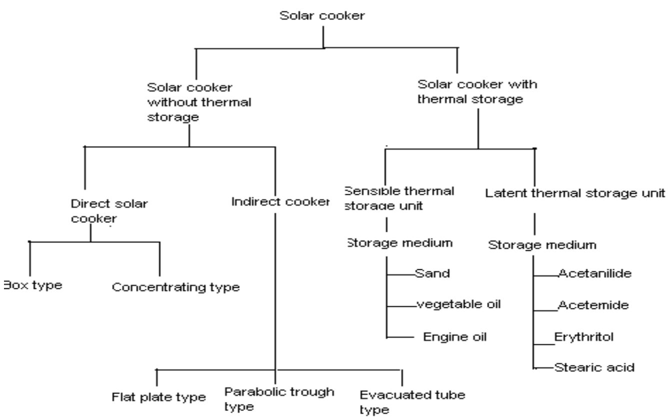


**Fig 1 Classification of solar cooker**

## 3. DIRECT TYPE SOLAR COOKER

The direct type solar cooker includes hot box and parabolic type concentrator cooker. Concentrator solar cookers in which the cooking pot is placed at the focus of a concentrating mirror have not been widely adapted due to need of continual adjustment of its orientation. Box and parabolic concentrator type solar cooker is widely used because of its simple design and operation. Solar cooker are becoming popular today because of fuel which this cooker required is available at free of cost (from sun) and it is environment friendly too. There is no loss of nutrients present in food during cooking because the food is cooked slowly at low heat. Solar cookers having so much of advantages but it has limitations too; cooker is able to cook food only in sunny days in day time only. So it limits there use in day time cooking only; night cooking is not possible with this type of cookers. For overcoming this problem we need a storage unit which stores the solar energy during day time and cooks food at night also or provides the opportunity of indoor cooking.

## 4. INDIRECT TYPE SOLAR COOKER

The indirect type solar cooker includes flat plate solar collector cooker and evacuated tube solar collector cooker. The indirect solar cooker use solar radiation to heat a thermal fluid that transports this heat to the place of cooking process. These types of solar cooker provide high thermal storage, temperature without tracking and at the same time cooking can take place in shadow or in conventional kitchen inside buildings. Due to the reversed cycle of during night and cloudy periods an effective heat transfer system is necessary to maximize the rate of heat transfer. Evacuated tube solar collector type solar cooker based on vacuum provided between tubes. In these types, evacuated tubes are used which are responsible for absorbing sunlight and converting it into usable heat. The tube is generally made of two glass tubes that are fused at the top and bottom. The inner tube has a solar absorbing material and the space between the two tubes is evacuated to form a vacuum. The evacuated tubes are made from borosilicate ensuring excellent strength and resilience. Evacuator is used to describe the process that expels the air from within the space between the tubes, forming a vacuum. A vacuum is an excellent insulator against heat loss.

## 5. DESCRIPTION OF SOLAR COOKER

In recent year's lot of research had done on solar cooker incorporating phase change material. Researchers used different types of solar cooker for conducting experiments to improve shortcomings of solar cookers. In general lot of work has been done on solar cooker incorporating phase change material and lot of work has to be done in coming future. List of work done on solar cooker are:

### 5.1 Box type Solar Cooker

Ramadan et al. [1] used sand to store solar energy of sun in the form of specific heat. They used sand because it is easily available and economical; in addition sand has high heat retention capability but it requires large volume to deal with. By using sand; cooker performance increased during the daytime and about 3hrs/day of indoor cooking was possible. It can also keep the food warm during night time as oven do.

Al-saad et. al. [2] develop a low cost clay type solar cooker. The importance of this cooker are that it is made from cheap, locally available materials, and no skilled labour required. In this, the replacement of the absorber plate with locally available black stones is done for absorbing more energy from the sun. The use of black stone instead of absorber plate resulted in a solar cooker capable of storing solar energy, hence making late cooking possible and more effective than conventional solar cooker.

Domanski et al. [3] investigated experimentally the possibility of cooking during off-sunshine hours by using phase change materials (PCMs) as storage media. For this, they designed two concentric cylindrical vessels were constructed with 2-cm gaps. This gap was filled with the PCMs as stearic acid or magnesium nitrate hexahydrate. The performance of cooker is evaluated in terms of charging and discharging times of the PCMs under different conditions. The overall efficiency of the solar cooker during discharging was found to be 3-4 times greater than that for steam and heat pipe solar cookers, which can be used for indoor cooking. During solidification of MNHH, temperature of cooking fluid was found to be in the range 78-84ºC which is higher than the lowest temperature required.

Thulasi das et. al. [4] studied the thermal model for the solar box cookers loaded with one, two, or four vessels. The method of Taha and Eldighidy has been utilized to estimate the enhanced solar irradiance on the cooker due to the flat reflector fitted to the cooker. The coupling of the Taha and Eldighidy method with the thermal model yielded the models for the box cookers. The energy balances ( equs 1 to 6 ), the equations for average temperature of region 1 and region 2 (equns 17 and 18) and the Taha and Eldighidy method provide a comprehensive model for the cooker.

Buddhi et al. [5] designed a box type solar cooker with latent heat storage and fabricated for the composite climatic conditions of India. The experimental results shows the feasibility of using a phase change material as the storage medium in the solar cooker, i.e. it is possible to cook the food even in the evening with a solar cooker having latent heat storage. The experimental results have also been compared with those of a conventional solar cooker. Commercial grade stearic acid was used as a PCM. Cooker was loaded with 150g rice and 300 g water at 4:00 pm for the second batch of cooking and exposed to solar radiation up to 5:30 pm. The solar cooker was opened at 8:00 pm and it was found that the rice was fully cooked and the temperature of the plate was still 65ºC which can keep the food hot for next two hours.

Funk et al. [6] presents a model for prediction of the cooking power of a solar cooker based on three controlled parameters (solar intercept area, over all heat loss coefficient and absorber plate thermal conductivity) and three controlled variables (insolation, temperature difference, and load distribution). The model basis is a fundamental energy balance equation, coefficient for each term in the model were determined by regression analysis of the experimental data.

Gaur et al. [7] studied the performance of the solar cooker made with special emphasis on the shape of lid of the utensils used in solar cooker. The study revealed that the performance of a solar cooker can be improved if a utensil with a concave shape lid is used instead of a plain lid, generally provided with solar cooker. The stagnation temperature for a utensil having a concave lid was about 2-7% more than the utensil with a normal lid. Water heating test showed that utensil have a concave shape lid took about 10-13% less time than that taken by utensils with a normal lid for the same temperature rise of water in both the utensils.

Buddhi et al. [8] present the experimental measurement of commercial grade Pcm stearic acid. They study the effect of temperature and thickness on transmittance have been studied. The study indicates that the effect of temperature on the transmittance of stearic acid in the liquid phase is not significant. The transmissivity of the liquid phase stearic acid is higher than the glass for the same thickness. Because of its low thermal conductivity and high transmitivity, it can be used as a transparent insulating material.

Sharma et al. [9] designed and developed a solar cooker with PCM storage unit to store solar energy during sunshine hours. The stored energy was used to cook food in the evening. Commercial grade PCM acetamide was used as a latent heat storage material. From the experimental results, one can conclude that (i) the storage of the solar energy does not affect the performance of the solar cooker for noon cooking and (ii) if a pcm having a melting temperature between 105 and 110°C is used, the cooking with the present design will be possible even during the night.

Rao et al. [10] discussed the role of the vessel inside the cooker. The heat has to penetrate the vessel and cook the food in a uniform pattern. The bottom surface of the cooking vessel and the lid are ineffective in the heat transfer process to the food. Raising the vessel by providing a few lugs will make the bottom of the vessel a heat transfer surface. This change improves the performance of the system by improving the heat transfer rates in both heating and cooling modes. When the vessel is kept on the lugs the circulation of hot air between the bottom of the vessel and the floor of the cooker improves the convective heat transfer to the contents in the vessel, since the effective area through which heat is transferred significantly. Hence, a reduction in cooking time is possible by keeping the vessel on some supports rather than directly on the floor. These support improve the cooker performance without involving much extra cost.

Buddhi et al. [11] experimentally evaluated thermal performance of solar box cooker having three reflectors with latent heat storage unit. Phase change material used for storage unit was commercial grade acetanilide which stored energy during day time. They conducted evening cooking experiments with different loads and loading times during the winter season. They investigated that night cooking was possible in solar cooker having three reflectors to enhance the incident solar radiation with the PCM storage unit.

Schwarzer et al. [12] studied solar cooking system with or without temporary heat storage. They investigate the possibility of indoor cooking and night cooking and used vegetable oil as the heat transfer fluid. The oil is heated up in the collector and moves by natural flow to the cooking unit, where it transfer parts of its sensible energy to the cooking goods in double walled pots. In the charging phase, the solar energy absorbed by the working fluid is storage in the oil-pebble tank and the plots shows temperature measurements at the outside walls. During discharging phase, when cooking is done after sunset, the heat released by the storage is estimated by the sensible heat gained by the water.

Subodh Kumar et al. [13] studied the thermal performance of box type solar cooker form heating characteristic curves. The top heat losses that constitute the major losses from the box type solar cooker has a strong influence on the thermal performance.

Harmim et al. [2010] [14] experimentally investigated the thermal performance of two identical box cooker; one having conventional absorbing plate and the other having finned absorbing plate. After studying; it is concluded that the finned absorber plate improves the performance of solar cooker by reducing the cooking time by 12% as compared to ordinary cooker. The stagnation temperature of box solar cooker equipped with finned absorber plate was 7% more than the ordinary cooker.

Harmim et al. [15] constructed and evaluated the performance of box type solar cooker employing an asymmetric compound parabolic concentrator. The cooker performance was expressed in the form of first figure of merit ($F_1$=0.1681) and second figure of merit ($F_2$=0.35). This cooker needs no tracking with time. This is the advantage of this type of cooker.

Suhail Zaki farooqui [16] presents a novel method for eliminating the need of frequent manual solar tracking of the most common type of solar cooker- the box type. The need for tracking along the azimuth has been addressed by the proposing a gravity based tracking mechanism that does not require any external power source. The required tracking energy is drawn from the potential energy stored in a spring attached to a water container. Water is discharged at a constant predetermined rate from the container, which caused the spring to un-stretch proportionally and hence rotate the solar cooker place over a support system. The whole system has been optimized for 6 h of cooking per day, during which no tracking should be required.

Sethi et al. [17] studied performance evaluation and solar radiation capture of optimally inclined box type solar cooker with parallelepiped cooking vessel design for efficient cooking especially in winter conditions. The cooking performance parameters of proposed inclined cooker coupled with new vessel design are compared with horizontally placed inclined cooker of same material and dimensions coupled with conventional cylindrical vessel design. First and second figures of merit (F1 and F2) for inclined cooker were 0.16 and 0.54 as compared to 0.14 and 0.43 for horizontally placed cooker. Time taken to boil water and cooking power was 37% less and 40% more respectively in parallelepiped shaped cooking vessel of inclined cooker as compared to conventional cylindrical vessel of horizontally placed cooker.

Sharma et al. [18] summarized the work done on solar cooking system incorporating phase change material. Their work is mainly focused on the thermal energy solar technology of solar cooker. Heat storage unit provides facility of cooking food at night also.

Muthusivagami et al. [19] studied all the research and development work done on solar cooker with and without thermal energy storage. They also discussed the new design of solar cooker incorporating phase change material having evacuated tube solar collector.

Saxena et al. [20] reviewed the literature of solar box cooker and suggested reforms in the existing design of solar cookers. Focus of their study on different components of solar cooker which are affecting the performance, working, economic aspects of cooker. They also designed a box cooker having wiper to remove vapor droplets from the bottom of the glazing during the cooking time. The wiper mechanism added in the design is helpful in reducing the cooking time and efficiently cook the food.

Cuce et al. [21] presents a thorough review of the available literature on solar cooker. The review covers a historic overview of solar cooking technology, detailed description of various types of solar cooker, geometry parameters affecting performance of solar cookers such as boosting mirrors, glazing, absorber plate, cooking pots, heat storage materials and insulation. Complex designs of solar cooker/oven with and without heat storage material are illustrated and furthermore possible methods to be able to enhance the power outputs of solar cooking systems are presented.

5.2 Parabolic type Solar Cooker

Ozturk [22] designed and tested a low cost parabolic type solar cooker (SPC) for evaluating the energy and exergy efficiency experimentally. The experimental time period was from 10:00 to 14:00 solar time. During the period, the daily average temperature of the water in the SPC was 333 K and the daily average difference between the temperature of water in the cooking pot and the ambient air temperature was 31.6 K. The energy output of the low cost parabolic type solar cooker varies between 20.9 and 78.1 W. The energy and exergy efficiencies of the SPC were in the range, 2.8-15.7% and 0.4-1.25% respectively.

Umanand et al. [23] modeled and designed a hybrid solar cooking unit. This cooking unit consists of parabolic trough collector, thermal storage tank, heat exchanger respectively. The heat was supplied by heat transfer fluid (servo-thermo oil) to the thermal storage unit by natural convection process. In this system supply of energy was two way, firstly energy supplied by the heat transfer fluid to the cooking pot and secondly energy supplied by LPG. This system provides the facility of using LPG and solar energy according to the situation. The hybrid cooking unit was very useful and had great advantage. The performance of this cooking unit was controlled by varying the fluid flow rate from collector to thermal storage unit and from thermal storage unit to the heat exchanger. The performance of this unit also depends on the diameter of pipes containing heat transfer fluid. The whole system was modeled with the help of bond graph approach.

Panwar et al. [24] reviewed on standard testing approach of solar cooker, energy and exergy analysis and economic aspect of solar cookers. Thermal performance of box type and concentrator type solar cookers in both laboratory and actual conditions are studied.

Mussard et al. [25] studied a solar cooker with heat storage unit, for high temperature, charging and simulation. A self-circulating loop is coupled with a heat storage and a parabolic trough for charging experiments. The loop is filled with thermal oil (Duratherm 630). The parabolic trough focuses the energy on a tube absorber. The storage is originally based on aluminium cylinders filled with nitrate salts immersed in the heated oil coming from the self-circulating loop. The salt provide latent heat to the heat storage (melting temperature: 215 to 225°C).

Mussard et al [26] studied a low cost small scale parabolic trough coupled with heat storage unit for cooking purposes. The heat storage is coupled with a self-circulating solar parabolic trough filled with thermal oil (Duraetherm 630). The storage is mainly oil-based but contains a significant part of nitrate salts in order to store energy with latent heat. The salts are contained in eight aluminium cylinders. The cylinders are connected to a top plate and the assembly is immersed into a container where the oil circulates. Once the storage is fully charged, a cooking vessel is filled with one liter of water and place on top of storage. After 38 min, the water starts boiling.

## 6. PHASE CHANGE MATERIALS

Phase change materials are those materials which stores energy in the form of latent heat. For solar cooker solid to liquid transition is preferred rather than liquid to gas; because solid to liquid transition is easy to handle rather than liquid to gas because of its compact volume. Phase change materials solve the problem of cooking at night or indoor cooking. They store solar energy in the form of latent heat. Phase change materials used for cooking should have following properties:

Melting point of phase change materials should be around 100 ° C or more. Phase change material should have high latent heat of fusion. Phase change material should have inert nature so that it doesn't react with environment and the container in which it is stored. Phase change material should not have combustible or explosive nature. Phase change material should be economical.

## 7. CONCLUSION

This review paper is focused on solar cookers for cooking during day as well as for off sunshine hours. Solar cookers can cook food during day time only. With the thermal storage unit, food can be cooked at late evening So that solar cooker with storage unit is very beneficial for the humans and as well as for the energy conservation. This paper presents the past and current research in this particular field for solar cookers.

## REFERENCES

[1] Ramadan, M. R. I., S. Aboul-Enein, and A. A. El-Sebaii. "A model of an improved low cost-indoor-solar-cooker in Tanta." Solar & wind technology 5, no. 4 (1988): 387-393.

[2] Al-Saad, M. A., and B. A. Jubran. "The performance of a low cost clay solar cooker." Renewable energy 1, no. 5 (1991): 617-621.

[3] Domanski, R., A. A. El-Sebaii, and M. Jaworski. "Cooking during off-sunshine hours using PCMs as storage media." Energy 20, no. 7 (1995): 607-616.

[4] Das, TC Thulasi, S. Karmakar, and D. P. Rao. "Solar box-cooker: Part I—modeling." Solar Energy 52, no. 3 (1994): 265-272.

[5] Buddhi, D., & Sahoo, L. K. Solar cooker with latent heat storage: "design and experimental testing". Energy Conversion and Management, (1995) 38(5), 493-498.

[6] Funk, P. A., and D. L. Larson. "Parametric model of solar cooker performance."Solar Energy 62, no. 1 (1998): 63-68.

[7] Gaur, A., Singh, O. P., Singh, S. K., & Pandey, G. N. Performance study of solar cooker with modified utensil. Renewable Energy, (1999) 18(1), 121-129.

[8] Buddhi, D., Sharma, S. D., & Sawhney, R. L. Performance test of a box type solar cooker: effect of load on the second figure of merit. International journal of energy research, 23(9), (1999): 827-830.

[9] Sharma, S. D., D. Buddhi, R. L. Sawhney, and Atul Sharma. "Design, development and performance evaluation of a latent heat storage unit for evening cooking in a solar cooker." Energy Conversion and Management 41, no. 14 (2000): 1497-1508.

[10] Rao, AV Narasimha, and S. Subramanyam. "Solar cookers—part I: cooking vessel on lugs." Solar Energy 75, no. 3 (2003): 181-185.

[11] Buddhi, D., Sharma, S. D., & Sharma, A. Thermal performance evaluation of a latent heat storage unit for late evening cooking in a solar cooker having three reflectors. Energy Conversion and Management, 44(6), (2003): 809-817.

[12] Schwarzer, K., & Da Silva, M. E. V. Solar cooking system with or without heat storage for families and institutions. Solar Energy, 75(1), (2003): 35-41.

[13] Kumar, Subodh. "Thermal performance study of box type solar cooker from heating characteristic curves." Energy conversion and management 45, no. 1 (2004): 127-139.

[14] Harmim, A., Belhamel, M., Boukar, M., & Amar, M. Experimental investigation of a box-type solar cooker with a finned absorber plate. Energy,35 (9), (2010): 3799-3802.

[15] Harmim, A., Merzouk, M., Boukar, M., & Amar, M. Mathematical modeling of a box-type solar cooker employing an asymmetric compound parabolic concentrator. Solar Energy, 86(6), (2012): 1673-1682.

[16] Farooqui, Suhail Zaki. "A gravity based tracking system for box type solar cookers." Solar Energy 92 (2013): 62-68.

[17] Sethi, V. P., D. S. Pal, and K. Sumathy. "Performance evaluation and solar radiation capture of optimally inclined box type solar cooker with parallelepiped cooking vessel design." Energy Conversion and Management 81 (2014): 231-241.

[18] Sharma, Atul, C. R. Chen, V. V. S. Murty, and Anant Shukla. "Solar cooker with latent heat storage systems: A review." Renewable and sustainable energy reviews 13, no. 6 (2009): 1599-1605.

[19] R.M. Murthusivagami, R. Velraj and R. Sethumadhvan, “Solar cookers with and without thermal storage - A review”, Renewable Sustainable Energy Rev. 14 (2010) 691-70.

[20] Saxena, Abhishek, S. P. Pandey, and G. Srivastav. "A thermodynamic review on solar box type cookers." Renewable and Sustainable Energy Reviews 15, no. 6 (2011): 3301-3318.

[21] Cuce, Erdem, and Pinar Mert Cuce. "A comprehensive review on solar cookers." Applied Energy 102 (2013): 1399-1421.

[22] Ozturk, H. H. Energy and exergy efficiencies of a solar box-cooker.International Journal of Exergy, 1(2), (2004): 202-214.

[23] Prasanna, U. R., and L. Umanand. "Modeling and design of a solar thermal system for hybrid cooking application." Applied Energy 88, no. 5 (2011): 1740-1755.

[24] Panwar, N. L., S. C. Kaushik, and Surendra Kothari. "State of the art of solar cooking: an overview." Renewable and Sustainable Energy Reviews 16, no. 6 (2012): 3776-3785.

[25] Mussard, Maxime, and Ole Jørgen Nydal. "Charging of a heat storage coupled with a low-cost small-scale solar parabolic trough for cooking purposes." Solar Energy 95 (2013): 144-154.

[26] Mussard, Maxime, Alexandre Gueno, and Ole Jørgen Nydal. "Experimental study of solar cooking using heat storage in