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A Scientific Pore over a Solar Cooking Systems

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***Abstract*: Energy is essential to life and all living organisms. It is fulfilling our daily needs: cooking, lighting, water heating and purifying, etc. It is also very significant to the human to maintain good health which is largely ignored. Three billion around people are using wood, cow dung, coal and other conventional fuels inside their homes resulting in indoor pollution. To conquer the said problem, solar energy cooking is the only solution. A large amount of solar energy is available in various parts of the world, which is pollution-free and easy to harness. More than 36% of the total generated energy is consumed for cooking in India. Hence there is a need to develop alternative cooking mode which will be easy, pollution-free and economical. However, the utilization of this form of energy at a large scale is only possible by developing an efficient cooking system with solar thermal energy storage technology and conventional cooking option which will enable the odd hours cooking.**

In this review paper, an attempt has been made to study the history and recent advancement in the field of solar energy cooking. The paper provides a detailed review of such kind of technology with cooking principle, types of cookers and their performance. Moreover, the review has been done on the use of Phase Change Material (PCM) in a solar cooking system which enables the night cooking.

Keywords: Cooking, Solar Energy, Pollution, Phase Change Material (PCM).

I. INTRODUCTION

Commonly used conventional energy sources for cooking are firewood, dung cake, kerosene, piped natural gas (PNG), liquefied petroleum gas (LPG), electricity, biogas etc. Three billion around people are using wood, cow dung, coal and other conventional fuels inside their homes for cooking resulting in indoor pollution. Every year more than 1.5 million people died because of indoor pollution mainly children and their mothers [1]. Many more people go through breathing problem daily. Furthermore, it's an obstacle to achieve development goals. Using wood as a fuel for cooking will destroy the forest also.

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Developing countries people are largely depended on the conventional source of energy as wood, coal, dung cakes etc. for cooking and on liquefied petroleum gas (LPG) and piped natural gas (PNG) for cooking in city areas. A developing country like India has an abundant amount of solar energy in the majority parts of it.

An average of 300 sunny days per year with an enormous land area, theoretically India provides $5X10^{12}$ kWh of clean and renewable solar energy every year across its cross-section [2]. Cooking by solar energy is simple, safe and environment-friendly. Hence solar energy is the energy which offers a solution for pollution-free cooking. Solar cooking is also identified as most suitable technology as it has numerous advantages such as no running cost, clean, reduces the hard work, easily available, safe and keeps the high nutritional value of food.

Although these advantages, there is a resistance to the acceptance of such kind of cooking. It depends on the sun and clear weather conditions. There are also a space, cost and convenience issue with solar cooking. As far as the cooking time is a concern, everybody wants fast cooking. Therefore good research is required to overcome this all difficulties and will increase the acceptance of such technology. Pia Piroschka Otte [3] concluded in his research that to implement solar cooking in routine, it has to be correlated with the socio-cultural belief of the region. As per F. Yettou et al. [4], research in the field of solar energy cooking is continuously going on but a very little is converted into real use. Major work on solar energy cooking is done for research purpose only.

A historical review of the solar cooking technology, solar cooking principle and detailed study on types of solar cookers are cover in this paper. An attempt also made to cover the recent development or advancement on the solar cooking system which enhancing the cooking efficiency, faster cooking and night cooking which is difficult in the ordinary solar cooking system. Moreover, a detailed study is also presented on the solar cooker with heat storage materials which enable the cooking at night.

II. PRINCIPLE OF COOKING

Initially, the maximum portion of the total energy supplied in cooking is consumed to raise the temperature of food which is kept in a cooker and then it is maintained steady for a while to get cooked food. Maximum types of food contain a high amount of water, and heating them to cooking temperatures requires nearly 1 Cal per kg per °C [5]. George O. G. Lof, concludes that low and high amount of energy supply in the form of heat may not show a large difference in the time required for cooking that must be taken several hours to cook.

For all types of cooking requirements, even if maximum temperature is below 100°C, it's necessary to provide energy source as heat at a considerably higher temperature if satisfactory cooking rates are to be obtained [6].

III. SOLAR COOKING HISTORY

People were not aware of cooking at the early age of civilization. They ate food as it was available naturally. German physicist named Tschirnhausen had done experiments on solar cooking from 1651 to 1708 as per Marlett Wentzel at el. [7]. He had boiled water by using a wide mirror to focus the sun's rays. Tschirnhausen work was published by Swiss scientist Horace de Saussure who also has invented a "hotboxes" to cook a fruit which was made of wood. He recorded 88°C temperature while cooking fruit with solar box type cooker. He was identified as the grandfather of solar cooking [8]. In the same period, a British soldier invented and patented a fairly sophisticated solar cooker in India. Shri M. K. Ghose designed and developed a box-type solar cooker around 1945 as a commercial product.

Countries like India and China encouraged the research on renewable energy as specifically on solar energy to alter the conventional fuel requirements for cooking. China held its first seminar on solar cooking in 1973 [6]. In 2010, R. M. Muthusivagami et al. [6] suggested that thermal energy storage is essential for odd hours cooking and given the new concept of the solar cooker with phase change material. In the same era, Prasanna U. R. [2] optimized the solar energy transport system for hybrid cooking applications which can be applied in newly designed cookers to enhance the efficiency. M .M. Valmiki et al. [9] proposed a new design in 2011 and manufactured a solar cooking stove which uses large Fresnel lens to concentrate the solar energy which improves the higher efficiency and safety of solar cooking. Smita B. Joshi and A. R. Jani [10] had designed and tested a photovoltaic and thermal hybridized solar cooker which has reduced the overall cooking time by connecting heater in it. Yogesh H. Shinde et al. [11] designed and developed an energy-efficient cooking system and tested it. Alberto Regattieri et al. [12] in 2016 suggested an innovative portable solar cooker which was built from the recycled cardboard packaging waste. The cooker can be used for various purposes like heating, cooking and boiling the water. They have tested many geometrical shapes and found that the parabolic configuration gives the best results with an average efficiency of about 14-18%. Abhishek Saxena and Nitin Agarwal developed a new hybrid solar box cooker (SBC). It has been developed and tested for thermal performance evaluation in the climatic condition of western Uttar Pradesh, India [13]. After testing and evaluating the performance of SBC, they have observed 45.11% thermal efficiency and cooking power has been estimated 60.20 W. Pinar Mert Cuce [14] in 2018 has suggested the Box type solar cookers with the heat energy storage material. He found that the cooker with thermal storage material was efficient around 35.3 to 21.7% as compared to the conventional solar cooker which has 27.6 to 16.9 %.

IV. SOLAR COOKING PRINCIPAL AND CLASSIFICATIONS OF SOLAR COOKERS

A solar cooker receives the solar irradiation and converts into heat energy, which is used to cook food, kept in the solar cooker. Initially, it adds the sensible heat to the pot and then food is being cooked after a certain period. As we have seen that there are so many types of solar cookers available and research continuously. They are classified mainly in three categories like box-type cookers, concentrating-type cookers, and non-focusing type cookers [4].

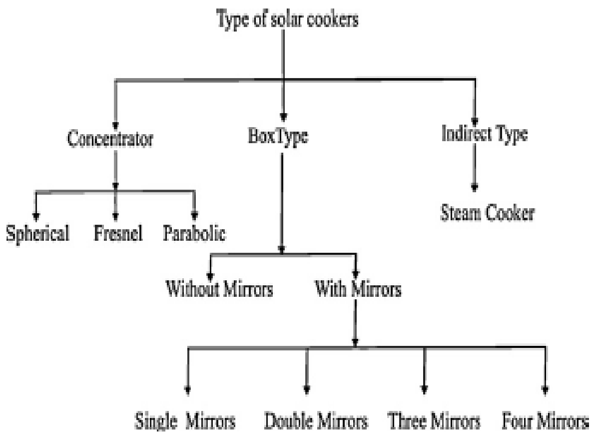

Fig. No. 1 Classifications of Solar Cookers

A. Box-type solar cooker

Box type of solar cooker is most common and conveniently used for two centuries. It is the simplest device to convert solar irradiation energy into heat energy. Heat energy finally cooks the food kept in the cooker [15]. Fig. no. 2 shows the simple box type of solar cooker. Box type solar cooker works efficiently even though there was a heat loss by surround wind, cloudy atmosphere or low ambient temperature. They were able to store food for 3 hrs after sunset [16]. Furthermore, performance may be enhanced by using reflectors and energy storage materials. The energy efficiency of the box type of solar cooker with thermal energy storage material is in between 35.3 to 21.7 % while it is 27.6–16.9% of conventional solar cooker [14].

Fig. No. 2 Box-type Solar Cooker

B. Concentrator type of solar cooker

Parabolic reflector type direct solar cooker concentrate the reflecting energy in a point focus and that energy can be utilized for direct or indirect cooking.

Fresnel lens, multifaceted mirrors, etc. are utilized to manufacture a concentrating type of solar cooker which is suitable for all type of cooking [4]. Fig no. 3 shows the best design of parabolic dish type solar cooker. It consists of a simple parabolic reflector and cooking pot which is located on a focal point of the reflector. A stand is provided to withstand the wind load.

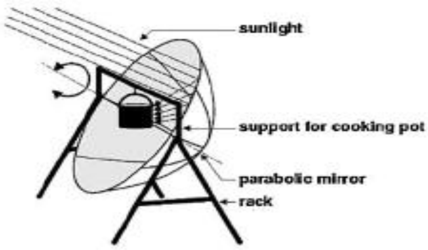

Fig. No. 3 Parabolic reflector type concentrating Solar Cooker

J. A. Duffle, G. O. G. Liif, and B. Beck [17] tested a solar cooker made with a thin plastic reflector in the shape of the parabola to cook food with the suitable support and food holder. They concluded that the rate of delivery of energy to a blackened vessel under desirable conditions of use is typically 300 to 500 watts. Hosny Z. and Abou-Ziyan [18] tested full tracked solar cooker named as a parabolic dish solar cooker in the winter season. They reported that the parabolic dish solar cooker has a higher rate of cooking (more than 2 to 6 times) and can achieve higher temperatures then box type solar cooker. They also have concluded that the use of windshield reducing the wind effect and it is confirmed by thermal analysis that reduction of 24 to 35 % in the heat loss from the receiver with the presence of a windshield.

C. Indirect type of solar cooker

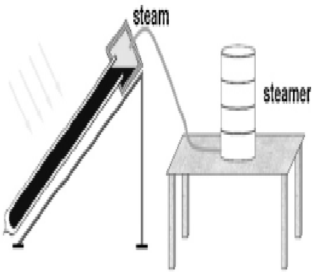

Fig. No. 4 Flat plate collector type indirect solar cooker

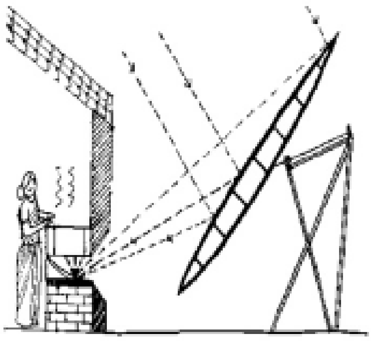

Fig. No. 5 Flat plate collector type indirect solar cooker

Flat plate and the parabolic reflector type indirect solar cookers (fig. no. 4 and 5) consist of vacuum tubes and parabolic reflector respectively to transfer the sun energy into food. Indirect type of solar cookers is most suitable for indoor cooking applications. Cost of such types of cookers is high compared with other types of the cooker. Mohammad Hosseinzadeh, et al. [19], they investigated the performance of a solar cooker consist of portable evacuated tubes with a stainless steel tank. They found that solar radiation and vacuum level are most effective parameter affecting the performance of the solar cooker. Hence selection of vacuum level in the tube is critical.

V. SOLAR COOKER WITH ENERGY STORAGE

Box type solar cookers receive direct solar irradiation while the indirect cookers use a heat transfer fluid to transfer the heat from the collector to the cooking unit. In both the type of cooking system, it's difficult to cook food in non-sunshine hours.

D. Buddhi et al. [20], designed and developed a solar cooker to store the energy during a day and it can be utilized to cook food in the evening or late night. Phase change material storage unit enables cooking in the late evening. R. M. Muthusivagami et al. [6], studied the solar cooker with and without the use of thermal energy storage material. They found that using thermal energy storage material, it is possible to design a modular indoor kitchen for community and residential application which may give the solution to each solar cooking problem. U.R. Prasanna and L. Umanand [21] optimized and designed an efficient energy transfer system for cooking. As per the review by Gang Li and Xuefei Zheng [22] on the thermal storage system, they suggested thermal energy stored solar cooker which can be used to enhance the performance of solar cookers. Further, K. K. Pillai and B. J. Brinkworth [23] found that phase change materials have a good capacity to store low-grade thermal energy in a compact system. They have optimized the different parameter relate with the PCM system, now can be used. S. K. Gupta [24] suggested materials for solar water heating system which is utilized further for new development. M. R. I. Ramadan et al. [25] designed a two pots solar cooker with energy-storing material (sand) which has improved the performance tremendously.

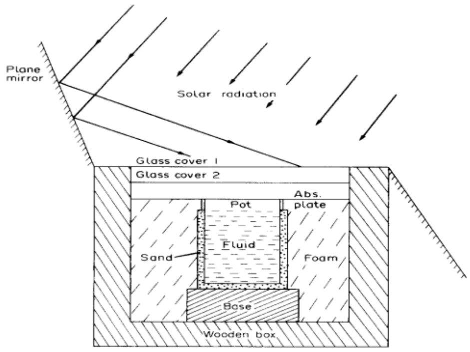

Fig. No. 6 A schematic diagram of PCM based solar cooker

The proposed (fig. no. 6) solar cooker which gives 28.4% overall energy conversion efficiency is best as compare to other available cookers. Further, they investigated that PCM such as paraffin may be good enough and future research can be done.

David I. Bushnel [26] constructed (fig. no. 7) a new heat exchanger that transfers rapidly the heat hence cooking time can be reduced.

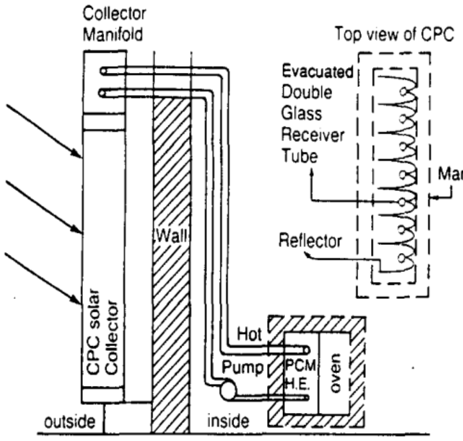

Fig. No. 7 A schematic diagram of PCM based solar cooker

A modular design is proposed which allows the numbers of energy-storing modules results in more heat distribution and convective heat transfer between temperature ranges of 215°C to 270°C. R. Domanski et al. [27] had tested experimentally the possibility of cooking during odd hours with phase change materials like stearic acid or magnesium nitrate hexahydrate. They reported that the resulting values of efficiencies are 3-4 times higher than the heat pipe and steam solar cookers which can be used in the kitchen. D. Buddhi and l. K. Sahoo [28] proved with the experiment that it is possible to cook food in the evening or late night is possible with phase change material. S. D. Sharma et al. [29] constructed a PCM storage unit for a solar cooker which receives and stored the energy during a day and can be utilized in the night for odd hours cooking. They noted that the storage of energy in the day doesn't affect the cooking efficiency in a day.

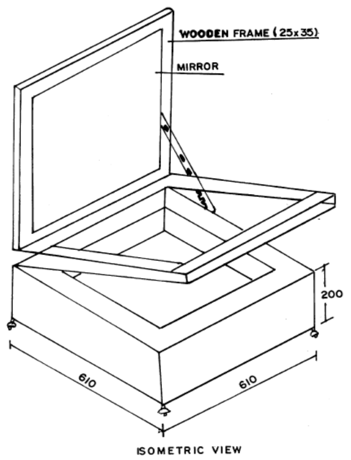

Fig. No. 8a Iso-metric view of a hot box storage solar cooker

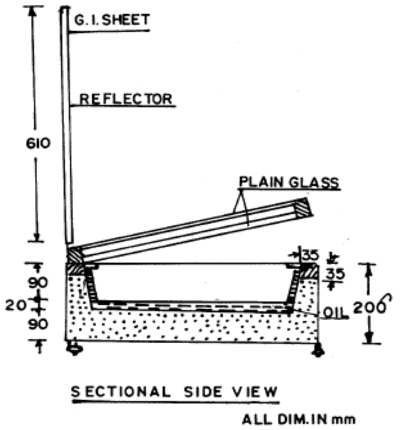

Fig. No. 8b Side view of a hot box storage solar cooker

N. M. Nahar [30] designed, fabricated and tested a hotbox solar cooker (fig. no. 8a and 8b) with engine oil as thermal energy storing material. They performed the experiment to cook green gram and rise in non-sunshine hours during 17:30 hrs and 20: 00 hrs in hot box type storage solar cooker which is not possible in the conventional box-type solar cooker without storage. They found that the efficiency of the proposed solar cooker is 27.5%. Beln Zalba et al. [31] had classified more than 150 energy storage materials and gathered all required details in one research paper. Klemens Schwarzer et al. [32] had built more than 250 cooking system and installed all over the world. From the experimental results, they had concluded that solar cooker has a very good chance for large scale cooking like in big families, schools, old age homes etc. provided with financial assistance. S.D. Sharma et al. [33] designed and tested a solar cooker with phase change material storage based on evacuated tube type collector.

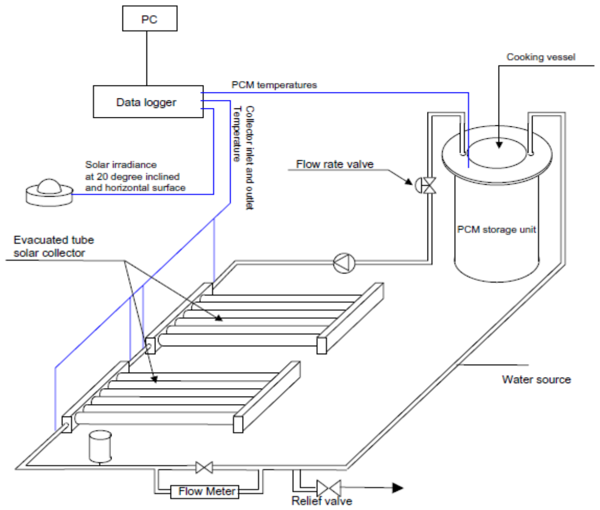

Fig. No. 9 Solar cooker based on evacuated tube solar collector with a PCM storage unit

The proposed system is shown in fig. no. 9 is quite expensive but can be used efficiently in community cooking requirements. They noted that it provides high PCM temperature up to 130 °C without tracking and allows also a kitchen cooking unlike that of conventional cookers.

Murat Kenisarin and Khamid Mahkamov [69] have registered that to minimize the use of a conventional source of energy and to protect the environment from greenhouse gas emissions, it is very essential to use renewable sources of energy for various energy requirements. However, the utilization of it at large scale is only possible by storing the energy. They have also suggested that before the commercialization of PCM based solar cookers, it is necessary to check it for 1000 thermal cycles.

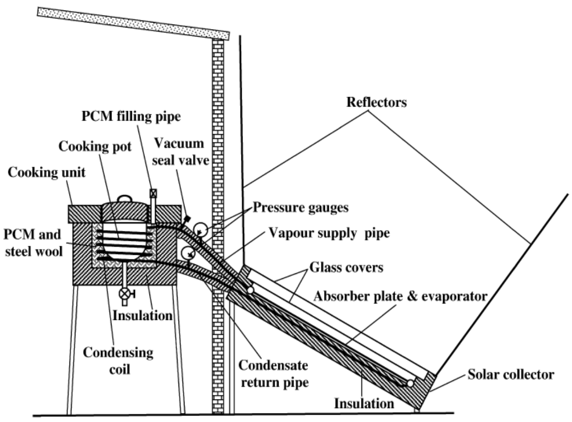

Fig. No. 10 Indirect Solar Cooker

H.M.S. Hussein at el. [70] designed an indoor solar cooker (fig. no. 10) with thermal energy storage material as magnesium nitrate hexahydrate (T_m = 89 °C, latent heat of fusion 134 kJ/kg). They found that the present design can cook a different type of food at any time.

VI. REVIEW RESULT

From reviewing this work, three areas for research and development are suggested,		
1.	2.	3.
Hybridization of Solar Thermal with PCM material, Solar Photovoltaic and Conventional Source of Energy like PNG.	Investigation on Large family or Community cooking with a hybrid solar cooker.	Use of the solar cooking system for Industrial Applications.

VII. CONCLUSIONS

A comprehensive review on solar cookers has been carried out and the following conclusions are made from the present study.

1. The solar energy source is one of the promising sources for cooking which will be free from pollution and maintain the vitamin values.

2. The people living in a rural area can use box-type direct solar cookers for their afternoon meal cooking which is commercially available in India.

3. A large scale community cooking, parabolic concentrating types of cookers are successfully being utilized.

4. Solar cookers with thermal energy storage material can be used for late-night cooking.

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