A COMPREHENSIVE REVIEW ON SOLAR COOKERS

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ABSTRACT:- Due to a constant demand for better utilisation of fossil fuels and the cost of producing electricity from the Renewable sources, we as a society have been, for quite some time, searching for either alternatives or a better way to utilise these resources to solve problems occurring on a daily basis. The paper is an attempt to shed some light on the developments on the solutions to the problem of drying food with the help of solar energy. The review paper consists of a carefully selected research papers on the development of various solar cookers which have had a significant impact on the subject.

INTRODUCTION

The increase in world's population demands increase in the energy needs. Annually, energy consumption progresses by an average of 1% in developed countries and 5% in developing countries [1, 2]. Fossil fuels are the major source of energy available today but they won't be sufficient enough to fulfil the increasing demand in the near future. Considering different factors like depletion of fossil fuels with their high prices and decline in world oil population and environmental issue renewable energy technologies have received remarkable attention at the international level over the last few years. Renewable sources play important role in sustainable development and they are environmentally friendly energy sources [3]. Among the renewable energy sources, solar energy is considered the most abundant and a viable option for thermal energy applications. As Thirugnanasambandam et al. [4] highlighted, the total annual solar radiation falling on the earth is more than 7500times of the world's total annual primary energy consumption. The annual solar radiations are reaching on the earth's surface, approximately $3.4*10^6$ EJ, is an order of magnitude greater than all the estimated non-renewable energy resources, including fossil fuels and nuclear. According to statistics, currently renewable energy resources supply about 14% of total world energy demand and their future potential is remarkable [5,6].

Food is essential for mankind to survive and fulfil their daily energy and nutrition requirements. Energy used for cooking plays an important role in the energy demands of residential buildings 86 [7]. In developing countries, such as those located in the temperate regions of Asia and 87 Africa, most residential energy consumption is due to cooking [8]. In India, about 36% of total energy is used for cooking [9], and in rural areas of Sub- Saharan Africa, it is 90% to 100% [10]. In developed countries, such as the United States, cooking accounts for 37% to 53% of total energy consumption [11]. Therefore, finding alternative led us to Solar heating systems which are efficiently used for cooking purposes instead of burning massive amounts of petrol derivatives or biomass sources. Solar radiation can be harnessed for cooking using a solar cooker. Solar cooking can be a sustainable solution for cleaner production and also reduce demand for conventional sources of energy. Compared with other cooking apparatus and their required fuel, solar cookers are cheaper and, in many cases, a good choice. Nonetheless, their disadvantages include
(I) a lack of social acceptance [12, 13], (ii) slower cooking than other methods [14],
(iii) not being available all the time [14], and (iv) the need for secondary cooking devices [14]. Here, recent advances in solar cooking technology are reviewed. The solar cookers are grouped into three different classifications based on structural types, heat transfer, and heat storage methods. Economic and environmental aspects are studied as well. Finally, the benefits and drawbacks of the current status of this technology are

investigated, and a pathway for future developments is suggested.

SOLAR COOKING BACKGROUND

The first solar cooker was built as a solar collector and was used to cook foods by a Swiss geologist in 1767 [15]. A few studies were later conducted on solar cookers until the first mass-produced solar cooker was invented in India in 1878 [16]. Before the invention of the box cooker, the technology suffered from many defects [17]. However, despite the many advantages of solar cookers, they are not widely used, especially for household cooking [18, 19]. In many developing countries with abundant annual solar radiation, employment of solar cookers has recently increased [20].

To compare solar cookers with other common cooking methods, Pohekar and Ramachandran conducted two studies on the prioritization of cooking devices in India [21, 22]. They ranked nine different devices by employing two different decision-making methods: multi-attribute utility theory and preference ranking organization method for enrichment evaluation. The devices were compared using thirty different criteria, including economic, social, technical, and commercial aspects. The authors reported that, after liquefied petroleum gas (LPG) stoves and kerosene stoves, solar box cookers are in third place, and solar concentrating cookers are in fourth place in the rankings.

Some scientists have tested different applications of solar cookers. Panwar et al. used a box solar cooker for animal food preparation called an animal feed solar cooker (AFSC). They compared AFSC with common rural cooking techniques in India. Their results indicate that the biomass technique, which is the most common cooking method in rural areas, can be completely replaced with AFSC. Further, using this device instead of petroleum fuel can lead to money savings and a decrease of CO2 emissions [23]. Among the various reviews of solar cookers, some have focused on local applications [24, 25]. Others have considered only one type of cooker, (e.g., box cookers [26], vacuum tube-based cookers [27], and cookers with a thermal storage unit [28-30]). Also, in some studies, multiple structural types of cookers are reviewed [31-33]. Recently, studies have been conducted on the economic aspects of solar cookers in specific regions, such as Lebanon [34] and India[35].

COMPARISON
BETWEEN DIFFERENT DESIGNS AND TYPES

Some researchers have experimentally compared the performance of different solar cooker types. Oz Turk compared a box cooker with a concentrating one. For the cases in this study, the box-type cooker showed a better performance. The author reported a maximum temperature of

344.4 K and 333 K, the maximum power as 60.2 W and 73.5 W, the maximum energy efficiency as 3.05% and 2.79%, and the maximum energy efficiency as 35.2% and 15.65% for the box type and the concentrating type, respectively [36]. Mirdha and Dhariwal investigated different designs of booster mirrors—both theoretically and experimentally—for a box-type solar cooker. Five different mirror arrangements from one mirror to five mirrors were studied. The design with five mirrors was reported to be the optimum design capable of cooking two meals per day and keeping the food warm in the late evening [37]. Kumar et al. proposed an energy analysis method for evaluating two types of solar box cookers: a normal box cooker and a truncated pyramid-type cooker. New parameters were introduced, including a quality factor, heat loss coefficient, peak energy, and the energytemperature difference gap product. They used experimental data from each type and reported values of 0.15, 4.09 W/m2K, 7.124 W, and 356.2 WK, respectively, for the pyramid type. For the normal type, the values were 0.14, 4.89 W/m2K, 9.95 W, and 305.1 WK, respectively [38]. In another study, Kumar et al. used the four parameters presented in their previous work to define a unified test protocol for different configurations of solar cookers. They compared four designs, including a box cooker, a direct- type parabolic cooker, an indirect-type parabolic cooker, and a trough cooker. The indirect-type cooker had the highest values of peak energy power and heat loss coefficient, and the box cooker had the highest quality factor [39]. Pandey et al. compared the energy efficiency of two conventional solar cookers: a box type and a concentrating type. Also, two different loads of water were tested: 1 and 2 L. In the 1-L load, the mean values of the energy efficiency were reported to be 4.9% and 7.1%, and in the2-L load, the mean values were 7.9% and 10.4%, for the box type and the parabolic types, respectively [40].

Lahkar et al. proposed a universal parameter for evaluating the optical and thermal performance of different cooker types called the opto-thermal ratio, which is the ratio of the optical efficiency to the heat loss factor. They experimentally tested a box cooker and a concentrating cooker and reported opto-thermal ratio values of 0.155 and 0.136, respectively. This indicates that the concentrating type had a better performance [41].

Mussard et al. compared a direct and an indirect concentrating solar cooker with similar characteristics, including a sun tracker system. Temperature rises of both devices were reported to be similar, but the cooking times differed. The time needed for boiling water was 27 minutes for the direct type and 38 minutes for the indirect type. Additionally, the time needed for frying meat was 12 minutes and 20 minutes for the direct and indirect types, respectively. The authors claimed that by improving surface contact between the PCM and the cooking vessel, cooking time was less than the time needed by the direct type [42].

A more detailed comparison of the different solar cooker types and the values of overall efficiency as reported in the literature are given in Table 2. The reason for choosing overall efficiency as the comparison factor is because this parameter appears in more studies than the other performance indicators.

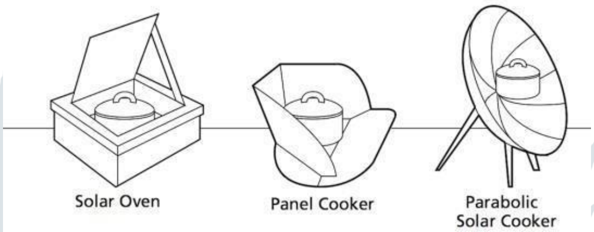

Figure 1: Types of Direct Solar Cookers

Solar cooker type	Additional equipment	Overall efficiency	Reference
Box cooker	---	26%	[43]
	---	32%	[44]
	2 glazing–Parabolic	10.69%	[45]
	mirror	21.9%	[46]
	Booster mirrors	38%	[47]
	Integrated PV panels	53%	[48]
	Finned Pot	54%	[49]
	Pyramid configuration		
Concentrating (Parabolic)	---	60%	[50]
	Insulation	53.45%	[51]
Panel cooker (Parabolic)	---	26.6%	[52]
	Two cooking pots	16.07%	[53]
	Three cooking pots	11.77%	[53]
Indirect parabolic cooker	---	21.97%	[54]
Indirect trough cooker	---	15.65%	[55]
Thermal storage (Box)	---	27.5%	[56]
Thermal storage (Parabolic)	---	55.6%	[57]
Thermal storage (trough)	---	10.2%	[58]

According to the overall efficiency of the different solar cooker types, the values reported for the parabolic cookers can be considered to be in the maximum range. The efficiency of these cookers is between 53.45% and 77%. On the other hand, the indirect trough cookers, with an overall efficiency of 15.7%, can be categorized in the minimum range. However, the parabolic panel cookers also have a low efficiency of between 11.77% and 35.27%. For the box cookers, a wide range of efficiency was reported, from 10.69% to 55.6%. In most cases, this value is more than 30%, and, accordingly, the box cookers can be placed in the mid-range classification. The panel cookers with the funnel configuration have shown significant performance, with an overall efficiency between 43% and 70.89%. For the cookers with a thermal storage unit, a
586 specific efficiency range cannot be determined because of a lack of data. Nevertheless, the same trend was observed in cookers without this unit. The indirect trough cooker has the lowest efficiency, and the parabolic cooker has the highest efficiency in this categorization. The box cooker ranks between these two.

CONCENTRATING SOALR COOKERS

Concentrating type solar cookers can be classified in different methods depending on their characteristics (Fig. 1) [49–51, 53]. For example, depending on the method of heat transfer to the cooking pot, concentrating types of solar cookers can be classified as direct type and indirect type [50,116]. In direct type solar cookers, solar radiation directly concentrates onto the cooking pot [58] while in the case of indirect designs, the solar energy is first utilized to produce high temperature and pressure steam and the same is then transported to the kitchen [117]. Two commonly available direct concentrating type solar cooker designs are parabolic dish and Scheffler dish. In the parabolic dish solar cooker (PDSC), the cooking pot is placed on a support attached to the frame of the solar cooker itself (Fig. 2) while in the case of Scheffler dish direct cooking system the cooking pot is kept at some distance away from it at the focal point of the secondary reflector (Fig. 3). The secondary reflector (which is kept near the focal point of the Scheffler dish) reflects the concentrated solar radiation received from Scheffler dish on to the cooking pot [40,118]. Presently in India, mainly three types of concentrators are being promoted by MNRE for cooking applications. These are i) Manually tracked paraboloid dish solar cookers (SK type, PRINCE type) to cook food for 10–40 people, ii) Fixed focus E-W automatically tracked ellipticalparaboloid dishes(Schefflerdish)andiii)Dualaxisfullytr acked Fresnel paraboloid dishes (ARUN® dish). Institutional solar cooking systems based on these technologies are under implementation for last few years with technical and financial support from MNRE. A comparison of the above mentioned solar cooking technologies is presented in Table 2. Though the three designs of concentrating types of solar cookers are presented in the Indian context, the same can also be considered for use in most of the developing countries. The designs have reasonably flexibility in terms of aperture area and consequently the amounts of food that can be prepared with them. While, it is possible to cook food indoor with the Scheffler direct and indirect solar steam cooking options, the use of parabolic cookers (SK-14, SK-23 etc.)

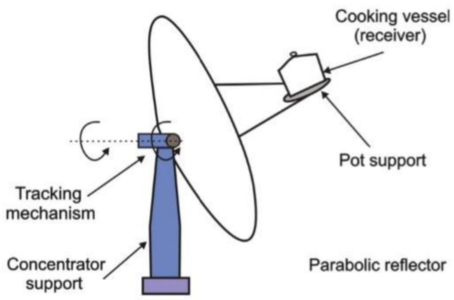

Figure 2: Concentrating solar cooker

Parameter	Parabolic	Scheffler (direct)	Indirect solar steam cooker Scheffler/Fresnel
Design	Circular (SK−14, 23, 30, 40) Square Parabolic (PRINCE −23, 40)	Elliptical/paraboloid	Elliptical/paraboloid
Range of Aperture area (m2)	1.4 − 7	7 – 16	7 − 16
Cooking mode	Direct	Direct	Indirect(steam)
Capacity (number of persons)	10–50	50–200	More than 200
Type of cooking (baking, frying, boiling etc.)	All	All	Boiling Type
Location of cooking vessels	On solar concentrator (outside in the sun)	Away from concentrator (in shed)	Away from concentrator (in shed)
Capital Cost (INR per sq. meter)	6000 −7000	14,000 – 16,000	16,000 – 20,000
Operation and maintenance	Easy	Relatively difficult	Difficult
Space constraint	Design with flexibility to move	Fixed unobstructed space is required	Fixed unobstructed space is required
Manpower requirementflexibility in cooking period	Unskilled No (Minimum 400–500 W/2 DNI required)	Semi-skilled Limited (heat storage device can be used)	Skilled Yes (steam can be stored for off sun-shine cooking period)
Manufacturing process	Easy (can be manufactured locally)	Relatively difficult	Difficult (steam generation, storage and transpiration requires high quality workmanship and processes

CONCLUSION

The sun is a free, renewable energy source. This advantage makes solar cookers an economical choice, especially if they have low construction costs. By investigating the performance of solar cookers, it was concluded that parabolic concentrating cookers have the highest efficiency. Panel cookers are mostly less efficient compared to the other types, and the efficiency of the box type is almost in a range between the other two cases. Moreover, it was determined that employing a heat storage unit can increase cooker efficiency and allow it to be used for breakfast and dinner meals, when solar thermal energy may not be available.

According to the current status of solar cookers on the worldwide market, recent advances have mostly focused on efficiency and performance. Other socioeconomic criteria must be addressed to make this technology a proper alternative to other existing cooking devices. To this end, a pathway for further investigations is proposed in this paper. Among the suggestions, working on the visual design of the cookers and developing a practical method for their indoor placement are the most important. To develop solar cooker technologies, further studies and experiments are needed to find the optimum configuration with low costs, high performance, and socially acceptable design.

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